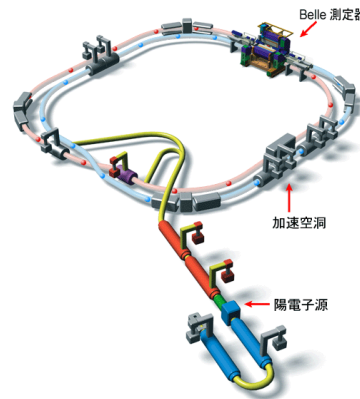
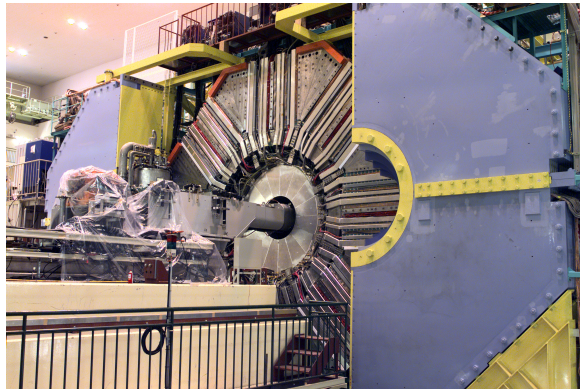


# Belle@KEKB, Belle-II@SuperKEKB

Tom Browder (University of Hawaii)

On behalf of the Belle and Belle-II collaborations  
as well as the US Belle I and Belle-II groups:

(Cincinnati, Hawaii, Princeton\*, PNNL\*\*, VPI and Wayne State)



History + Physics + LHC Synergy

Nichibei 日米 (US-Japan) 30<sup>th</sup> anniversary meeting, October 20, 2010



## Past and Present

- In the 1990's the Belle experiment greatly benefited from Nichibei supported R+D on readout for silicon vertex detectors, high precision TOF counters and detection of muons and  $K_L$ 's via RPC's.
- In 2010: we are conducting R+D for Belle-II with a strong collaboration involving a consortium of US universities, Nagoya University and KEK. The main focus is high momentum particle ID (with SLAC) and beam monitoring.

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Bファクトリー実験に参加している研究教育機関

ブドカー研究所 チェンナイ数値科学 千葉大学  
 ヨンナム大学 シンシナチ大学 イーファ女子大学  
 ギーセン大学 キョンサン大学 ハワイ大学  
 広島工業大学 北京 高橋研

モスクワ 高エネルギー 研究所 モスクワ 理論実験物理研  
 カールスルーエ大学 神奈川大学 コリア大学  
 クラコウ原子核研 京都大学 キンボック大学  
 ローザンヌ大学 マックスプランク研究所  
 ヨセフステファン研究所 メルボルン大学

名古屋大学 奈良女子大学 台湾 中央大学  
 台湾 連合大学 台湾大学 日本医科大学 新潟大学  
 ノバコリカ 科学技術学校 大阪大学 大阪市立大学  
 ハンジャブ大学 北京大学 ヒッツバーグ大学

BaLグループ <http://bael.kek.jp>  
 ENEPグループ <http://www.kek.jp>  
 KEKBグループ <http://kek.jp>

プリンストン大学 理化学研究所 佐賀大学  
 中国科学技術大学 ソウル大学 信州大学  
 サンキンカン大学 シドニー大学 京都大学東京  
 タタ研究所 東邦大学 東北大学 東北学院大学  
 東京大学 東京工業大学 東京農工大学  
 トリノ 核物理研 富山商船高等専門学校  
 ウェイン大学 ウィーン高エネルギー研  
 バージニア工科大学 延世大学  
 高エネルギー加速器研究機構

3

Poster Designed by T. Iijima, Y. Iwasaki,  
 S. Kataoka, N. Katayama, K. Miyabayashi

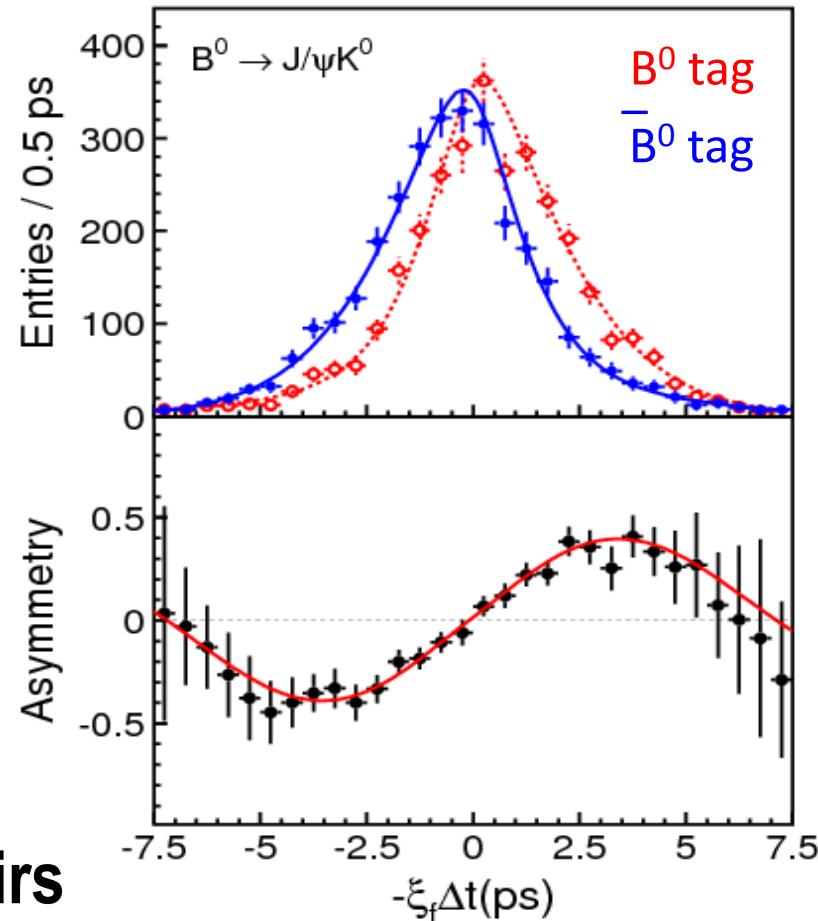
2008:

Critical Role of the B factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's.

CP violating effects in the B sector are  $O(1)$  rather than  $O(10^{-3})$  as in the kaon system.

The cartoon refers to Belle  $B^0 \rightarrow J/\psi K^0$  data



535 M  $B\bar{B}$  pairs

previous measurement  
 $\sin 2\phi_1 = 0.652 \pm 0.044$   
 (388 M  $B\bar{B}$  pairs)

$$\sin 2\phi_1 = 0.642 \pm 0.031 \text{ (stat)} \pm 0.017 \text{ (syst)}$$

$$A = 0.018 \pm 0.021 \text{ (stat)} \pm 0.014 \text{ (syst)}$$

4

(An update with 50% more  $L_{\text{eff}}$  coming soon)

hep-ex/0608039, PRL

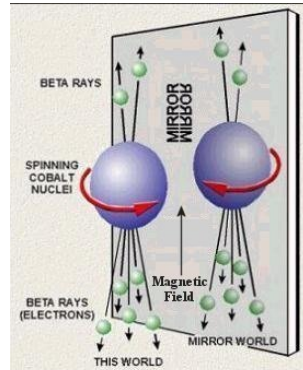
# Nobel Prizes from Surprising Discoveries about *Weak Interactions of Quarks*



T.D. Lee



C.N. Yang



Maximal P violation



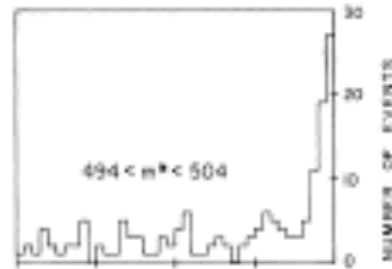
1957



J. Cronin



V. Fitch



Small CP violation



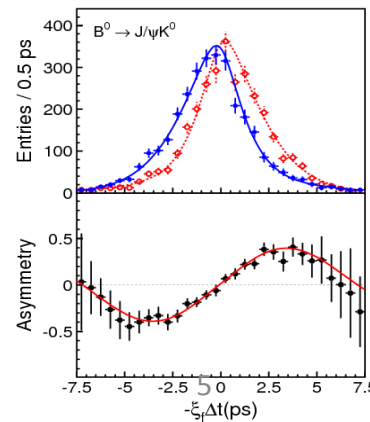
1980



M. Kobayashi



T. Maskawa



O(1) CP violation and 3 generations

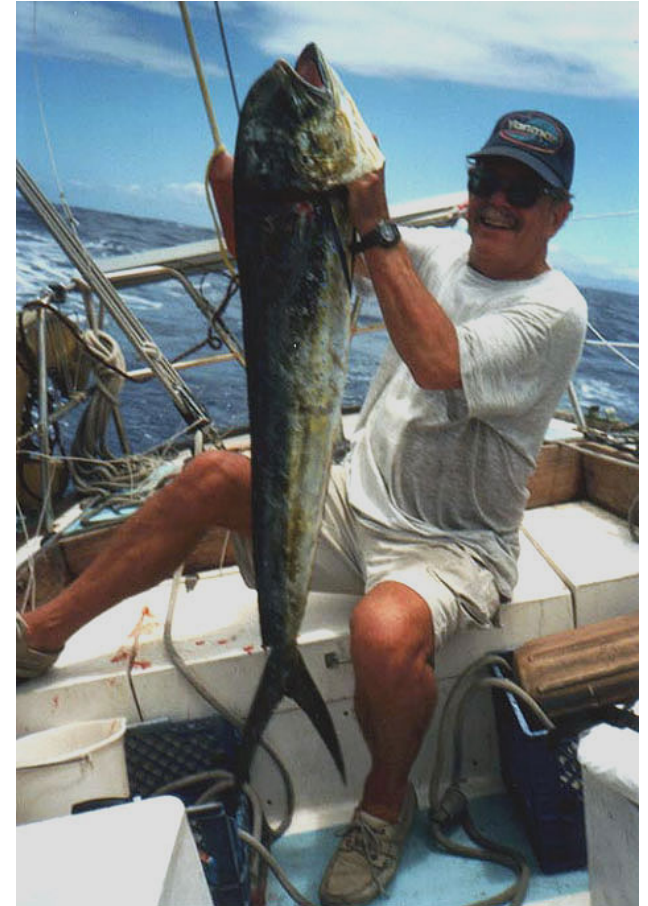
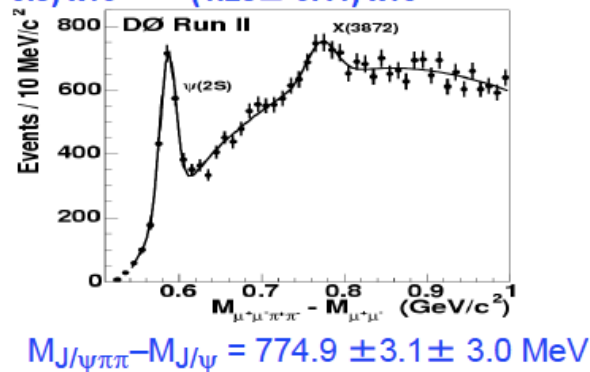
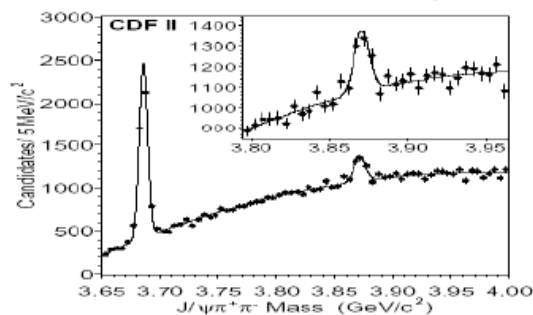
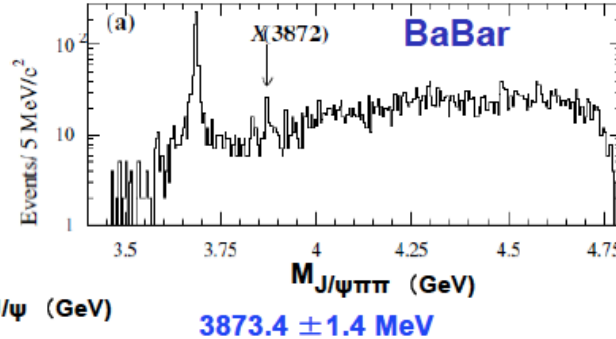
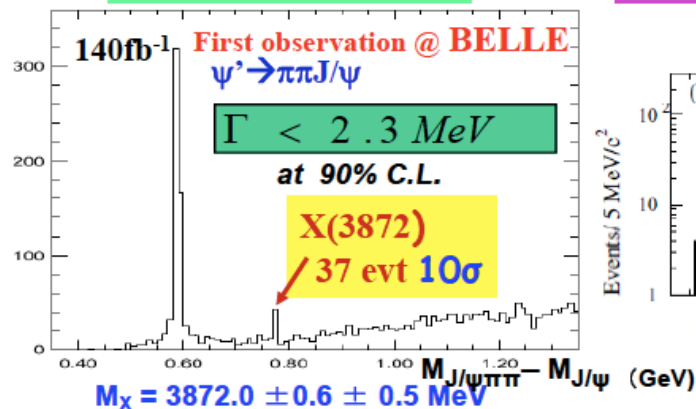


2008

In addition to observing CP violating phenomena, Belle discovered a series of *unexpected* new particles.

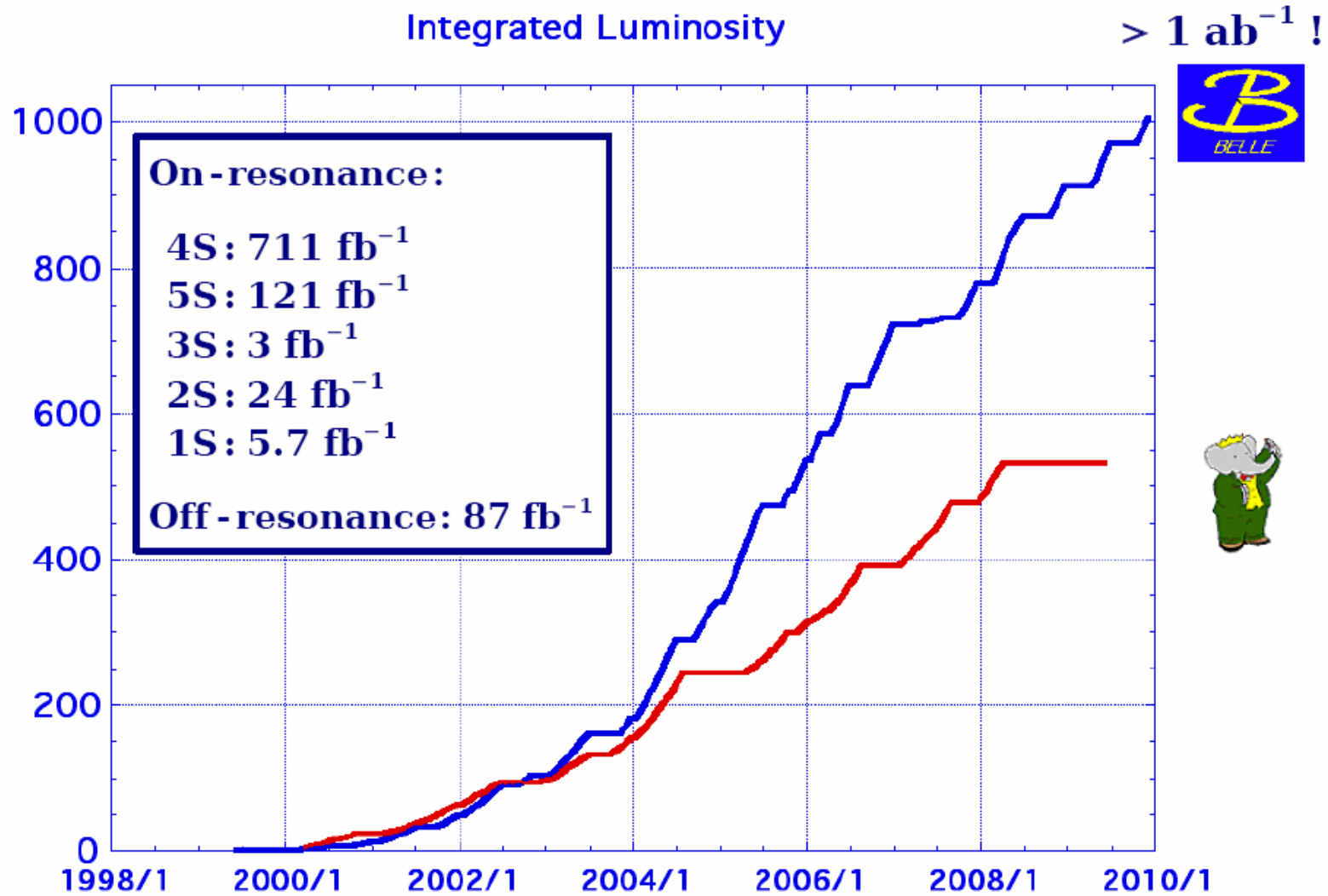
## Discovery of X(3872) in 2003

Belle PRL 91, 262001 (2003)



Followed by the discovery of the Y (3940) and a charged Z state.

**Belle/KEKB** Integrated luminosity passed 1000 fb<sup>-1</sup>  
(→ have to switch to new units, **1 ab<sup>-1</sup>**)



Peak lumi record at KEKB:  $L = 2.1 \times 10^{34} / \text{cm}^2 / \text{sec}$  with crab cavities

## KEKB Final Beam Abort Ceremony



Belle実験グループ代表の一人、ハワイ大学のトム・ブラウダー教授は「11年前にKEKBとBelleが実験を開始したとき、世界最高のルミノシティを達成すると外部の人は予想していなかった。ここに至るまでの道のりは平坦ではなかったが、小林・益川両博士にノーベル賞をもたらしたB中間子のCP対称性の破れの確認など、世界各地の大学院生や研究者が数多くの論文を執筆するための重要なデータを得ることができた。これらのデータで得られた科学上の知見の大きさははかりしれない。」と述べた。

<http://www.kek.jp/ja/news/topics/2010/KEKBfactory.html>

Intense Analysis Phase: *Just completed **reprocessing***

*Belle Datasets listed below*

(units in  $\text{fb}^{-1}$  )

- Upsilon(5S) 120.6 on-resonance ( $B_s$  physics)
  - Upsilon(4S) 710.5 on-resonance/83.3 off
- 

- Upsilon(1S) 5.7 on/1.8 off (100M 1S)
- Upsilon(2S) 24.1 on/1.7 off (159M 2S)
- Upsilon(3S) 2.95 on/0.248 off

Datasets in red are the world's *largest* samples

# Are we done ?



$$\frac{n_B}{n_\gamma} = (5.1^{+0.3}_{-0.2}) \times 10^{-10}$$

$$KM \sim 10^{-20}$$



Из доклада С. Окубо  
при большой температуре  
для Вселенной с нуля и нуля  
по ее кривой фигуре

НАРУШЕНИЕ CP-ИНВАРИАНТНОСТИ, C-АСИММЕТРИЯ  
И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д. Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует

Too small by 10 orders  
of magnitude in the SM

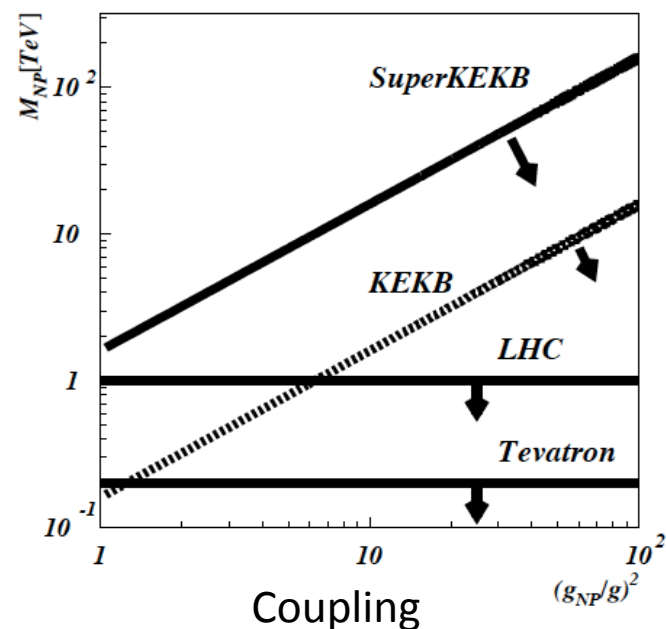
## Why a SFF is so important.

A Super Flavor Factory (SFF) studies processes that are 1-loop in the SM but may be  $O(1)$  in NP : FCNC, mixing, CPV.

Current experimental bound is  $O(10-100)$  TeV depending on NP coupling. Thus if the LHC finds NP at  $O(1)$  TeV it *must* have a non-trivial flavor structure.

Even if no new particles are found at the LHC, current SM couplings provide sensitivity to new particles at a SFF.

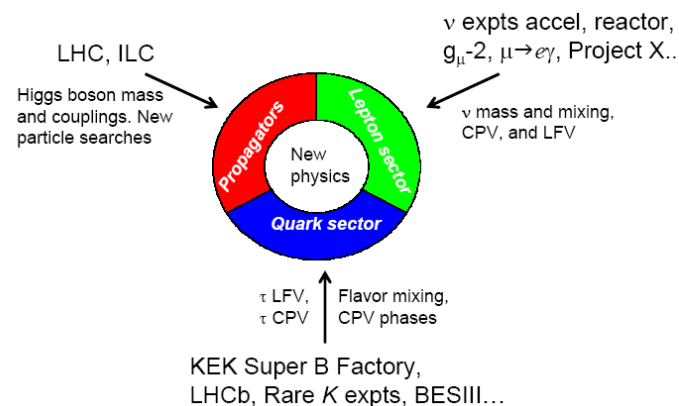
There must be new sources of CPV to explain the BAU.



Minimal Flavor Violating (MFV)

Enhanced Flavor coupling

The Super B Factory is part of a **Unified** and **Unbiased** Attack on New Physics



# New Physics

(in the Weak Interaction)

Attempt to go beyond Kobayashi-Maskawa

*Are there **new particles** beyond those in the SM, which have different couplings (either in magnitude or in phase) ?*

*Supersymmetry is **an** example (~40 new phases). Extra Dimensions is another.*

# Is there a small NP phase in $B^0 - \bar{B}^0$ mixing ?

E. Lunghi, A. Soni

CKMFitter:

10-20% NP  
contributions  
allowed

Indirect meas:

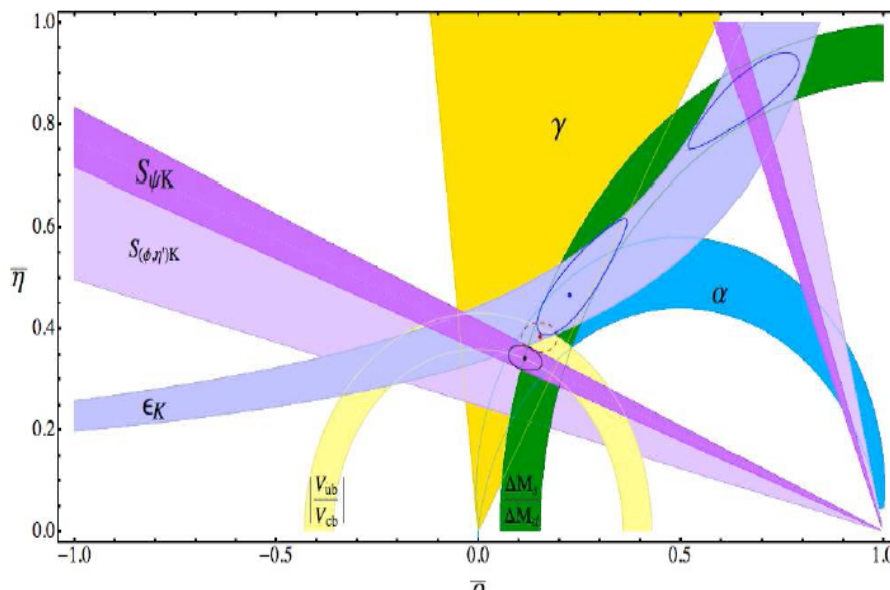
$$\sin(2\phi_1) = 0.87 \pm 0.09$$

(about  $\sim 2\sigma$  deviation)

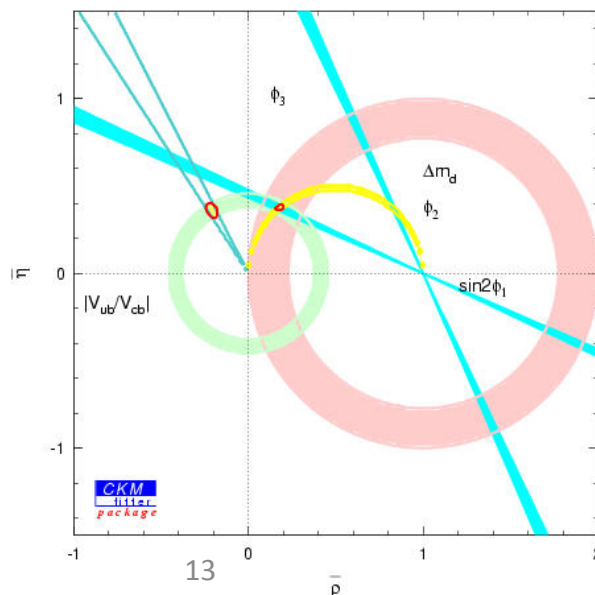
c.f. direct  $0.672 \pm 0.023$

Larger deviation

Penguin  $0.58 \pm 0.06$

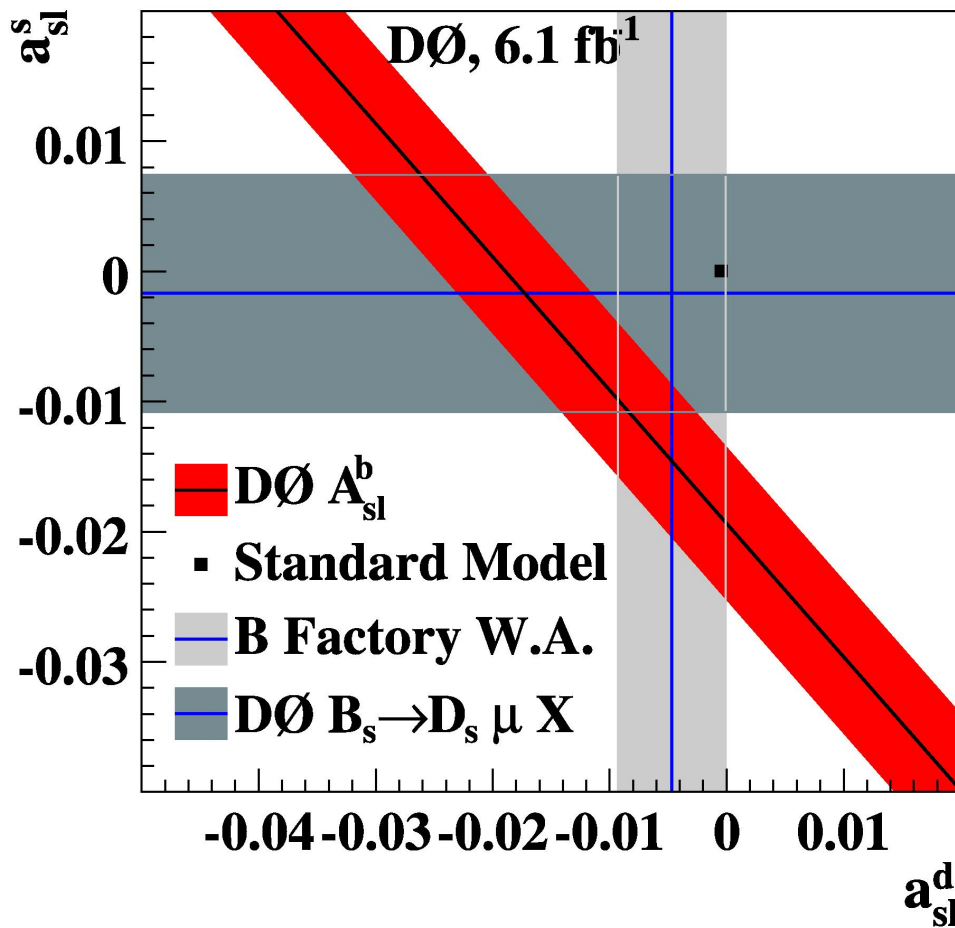


Use the  
latest lattice  
results for  
 $\epsilon_K$

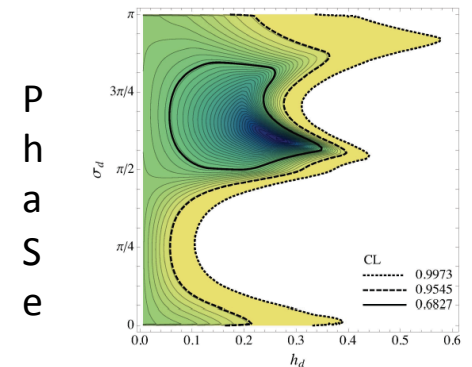


50  $\text{ab}^{-1}$

# New Physics Hint from DØ: Anomalous Same Sign CP dilepton asymmetry



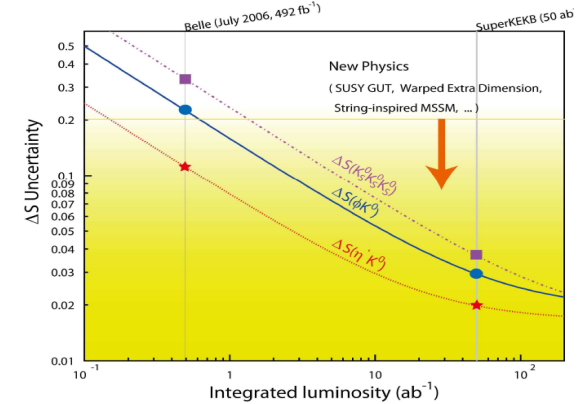
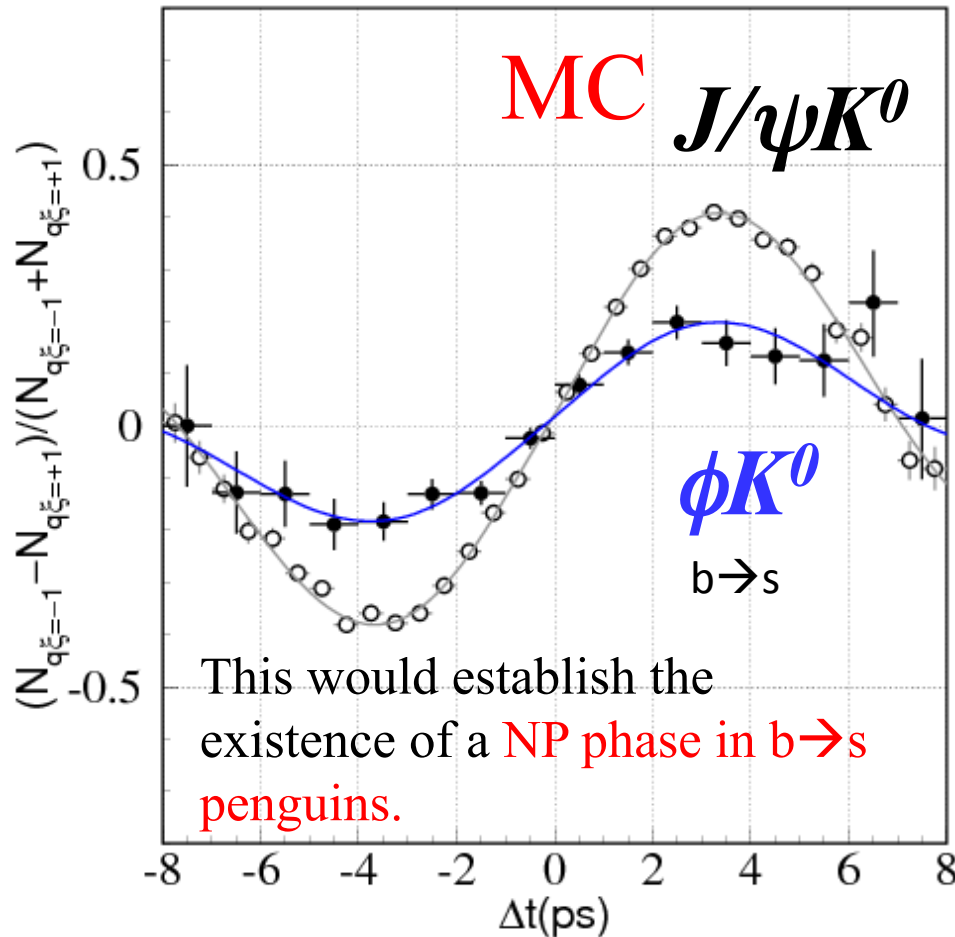
*Suggestive of a new physics phase in either  $B_s$  and/or  $B_d$  mixing*  
(examples: arXiv: 1005.4238, 1006.4321)



**Amplitude of NP**

# *Not such a wild extrapolation:*

$B \rightarrow \phi K^0$  at 50/ab with  $\sim$ present WA values

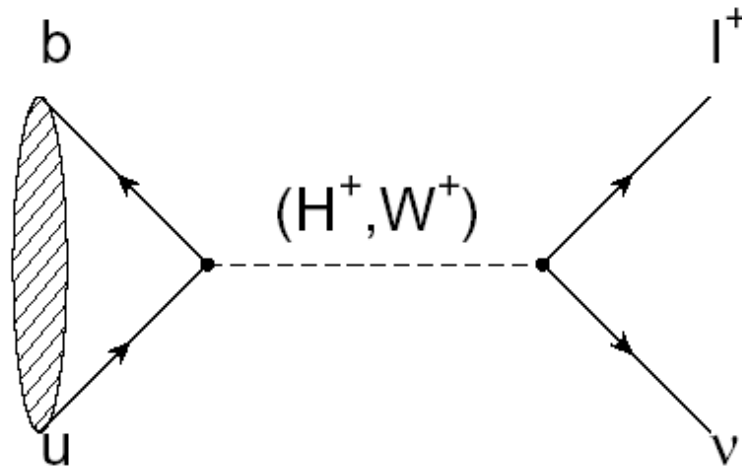


Compelling measurement in a clean mode

$$B^+ \rightarrow \tau^+ \nu_\tau$$

(Decays with *Large* Missing Energy)

Sensitivity to new  
physics from  
charged Higgs



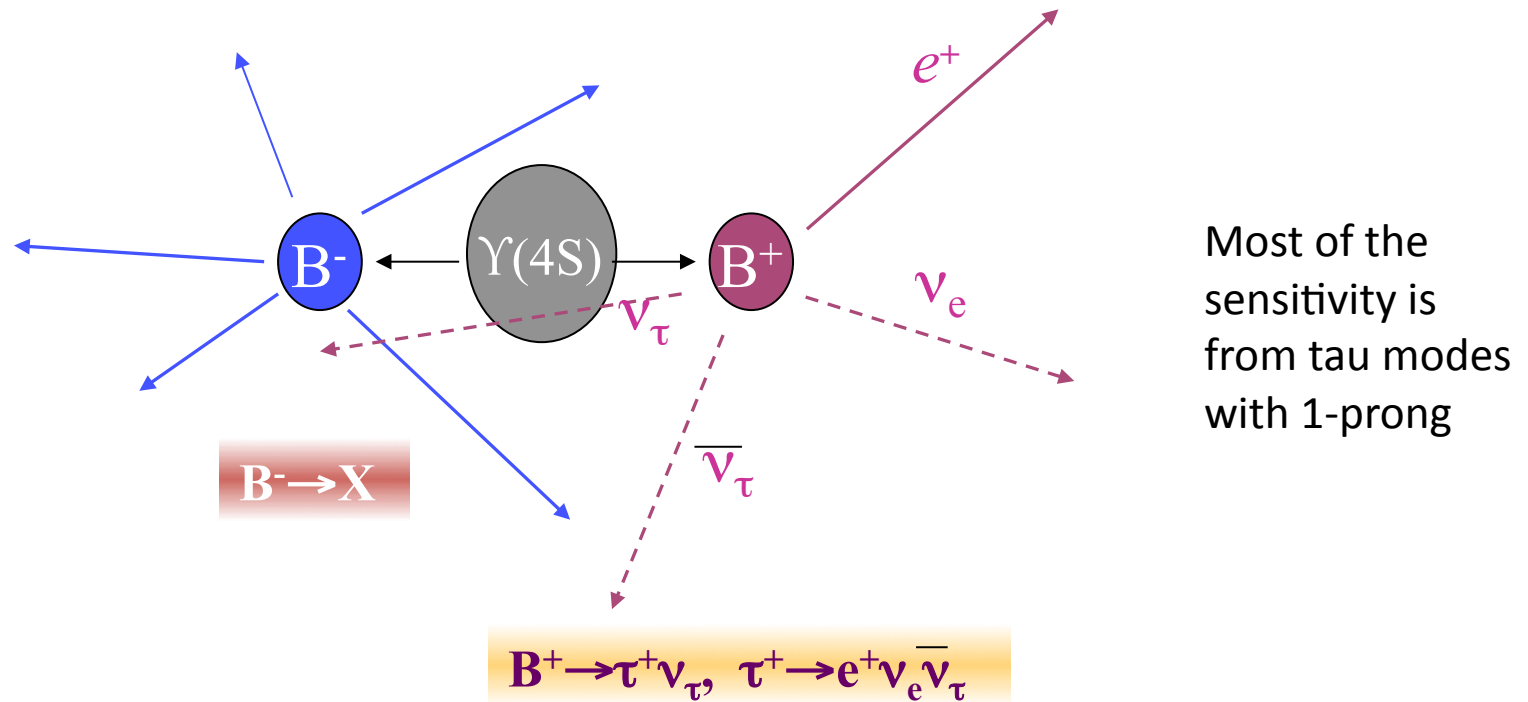
$$\mathcal{B}(B^+ \rightarrow \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$



*The B meson decay constant, determined by the B  
wavefunction at the origin*

( $|V_{ub}|$  taken from indep. measurements.)

# *Why measuring $B \rightarrow \tau \nu$ is non-trivial*

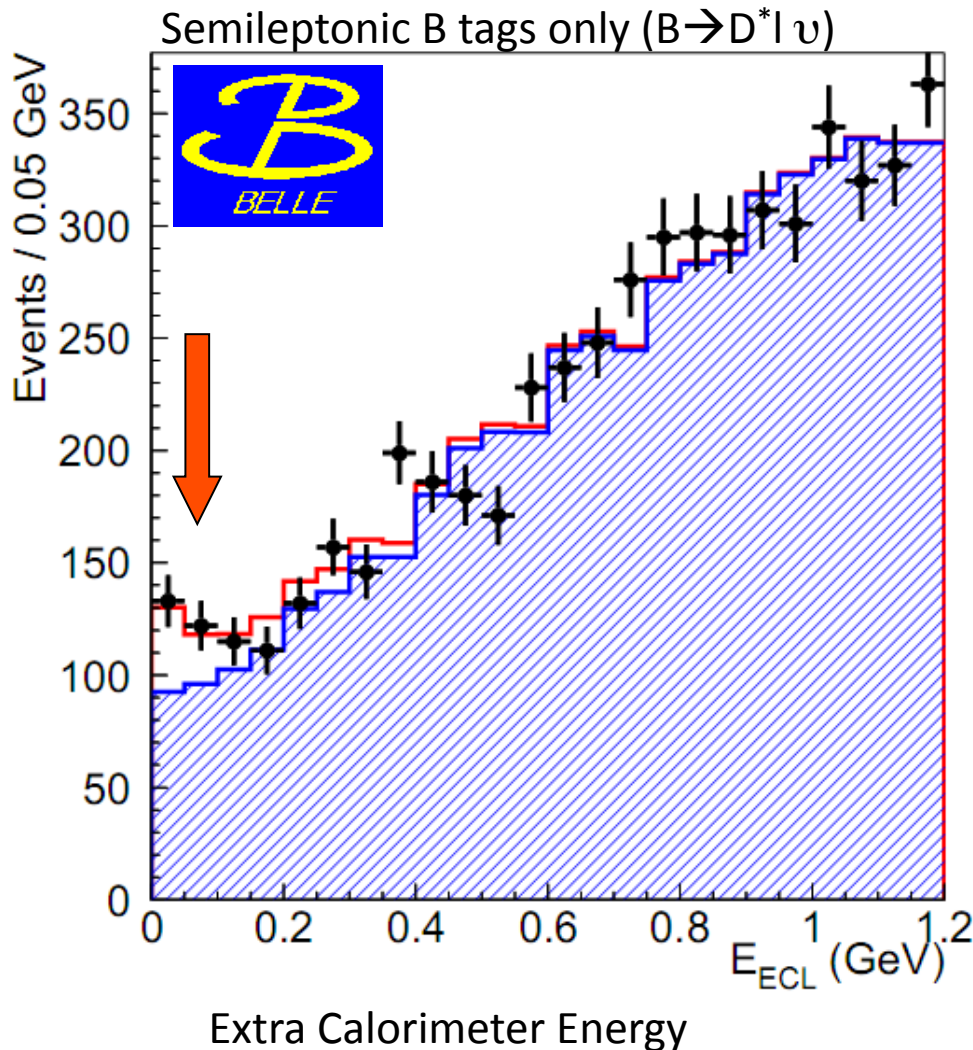


*The experimental signature is rather difficult:  
 $B$  decays to a **single charged track + nothing***

(This will be difficult at a hadron collider)<sup>17</sup>

# Latest Belle $B \rightarrow \tau \nu$ Result

(arXiv: 0809.3834, to appear in PRD-RC)



$$N_{\text{sig}} = 143^{+36}_{-35} (\text{stat})$$

$$\mathcal{B}(B \rightarrow \tau \nu) = (1.54^{+0.38+0.29}_{-0.37-0.31}) \times 10^{-4}$$

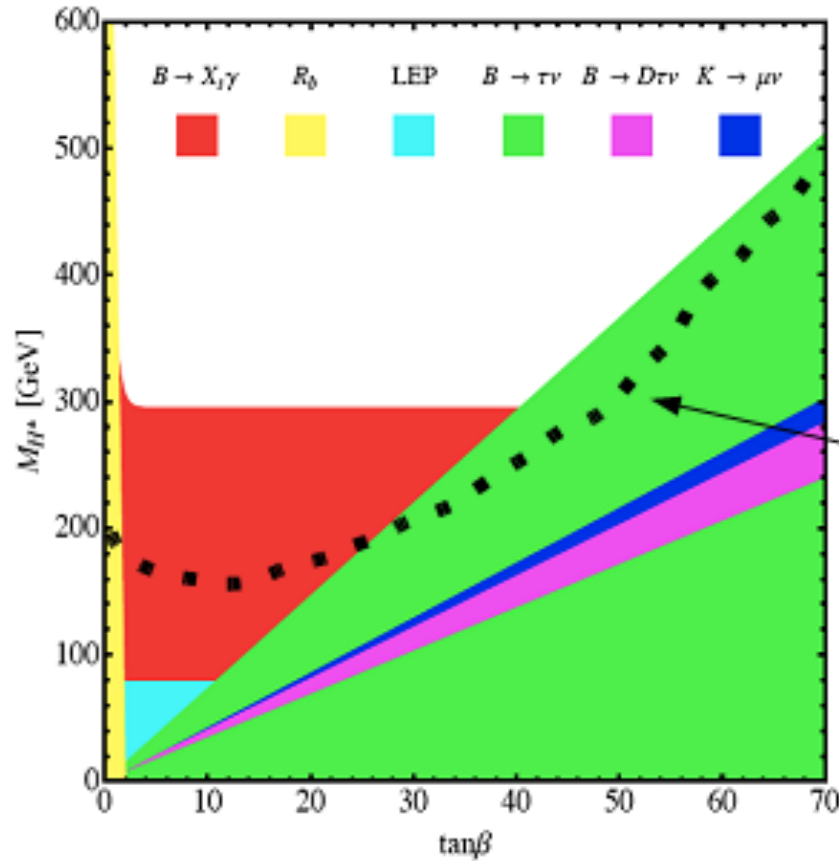
Dominant systematic errors for  $\mathcal{B}(B \rightarrow \tau \nu)$ :  
BG MC Statistics (8.5%), Tagging Efficiency (14%)  
Peaking BG Uncertainty (8%)

3.6 $\sigma$  significance  
including systematics.

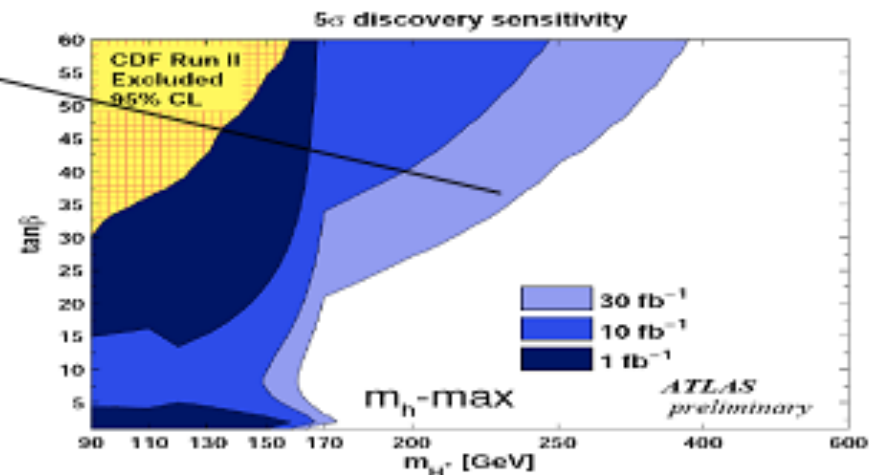
Confirmation of previous Belle  
result with hadronic tags (more  
precise)

**Still above SM expectation,  
discrepancy  $\sim 2.4\sigma$**

# *B Factories versus LHC (ATLAS) for the charged Higgs*



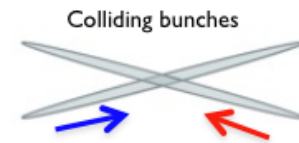
Current flavour constraints are already very competitive with LHC expected direct search sensitivity for charged Higgs



U. Haisch, hep-ph/0805.2141; ATLAS curve added by *Steve Robertson*

Also see (MSSM), D. Eriksson, F. Mahmoudi and O. Stal

# SFF Physics requires Luminosity



Colliding bunches

New Superconducting / permanent final focusing quads near the IP



Add / modify rf systems for higher currents.

Low emittance positrons to inject

New positron target / capture section

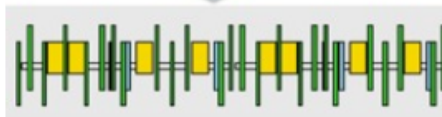
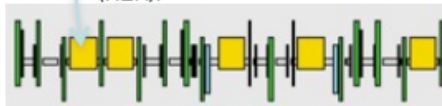
$$L = \frac{\gamma_{\pm}}{2e r_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left( \frac{I_{\pm} \xi_{\pm y}}{\beta_y^*} \right) \left( \frac{R_L}{R_y} \right)$$

**x40 Gain in Luminosity**

(Must reduce  $\sigma_y$  from 1  $\mu\text{m}$   $\rightarrow$  59 nm)

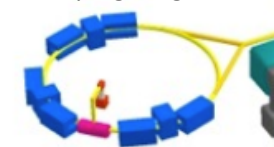


Replace long TRISTAN dipoles with shorter ones (HER).



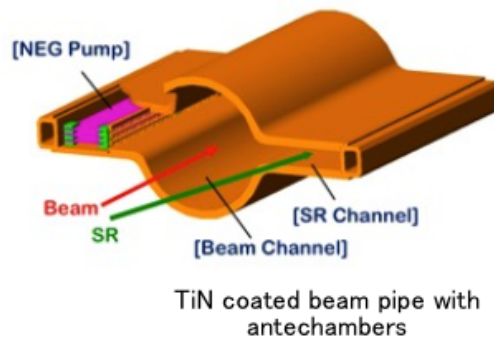
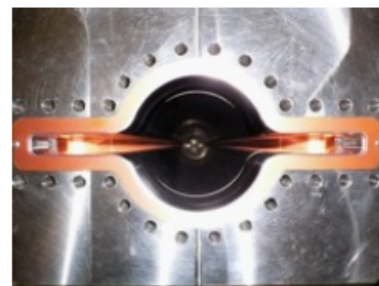
Redesign the HER arcs to squeeze the emittance.

Damping Ring



Low emittance gun

Low emittance electrons to inject



# Features of Belle II detector @Super KEKB

High momentum PID with low fake rates to observe and study  $b \rightarrow s$  and  $b \rightarrow d$  penguins (US contribution)

In contrast to LHCb, superb **neutral detection** capabilities.

e.g.  $B \rightarrow K_S \pi^0 \gamma$  can be used to detect right-handed currents

Capable of observing rare “**missing energy modes**” such as  $B \rightarrow K \nu \bar{\nu}$  with B tags. Hermeticity is critical.

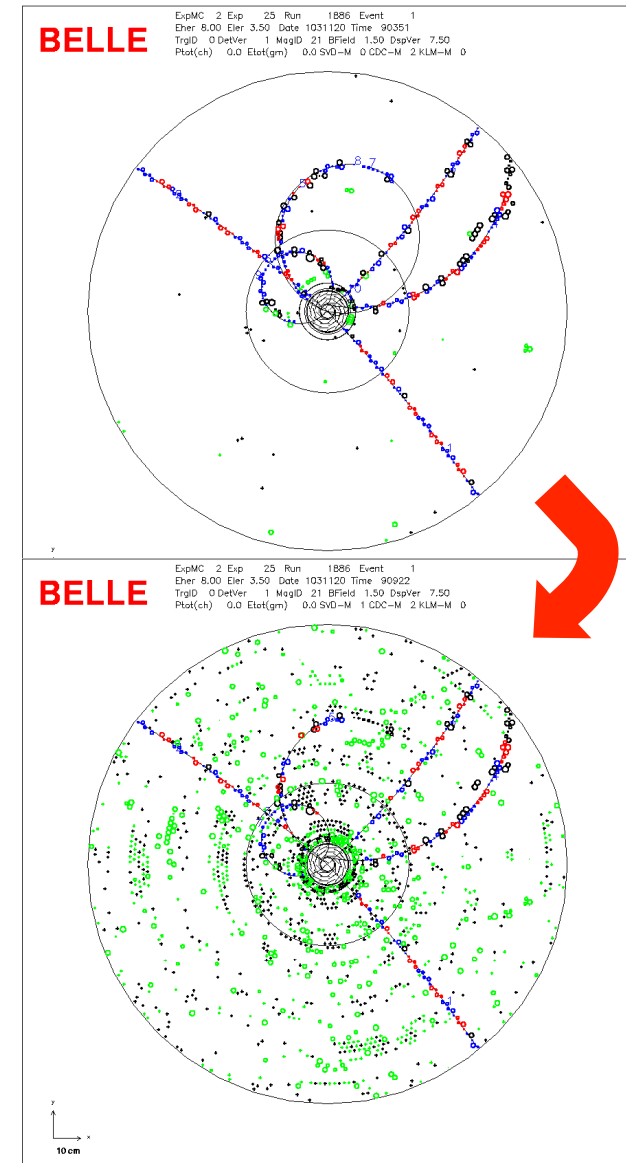
Issues:

**Higher background due to Touschek ( $\sim \times 20$ )**

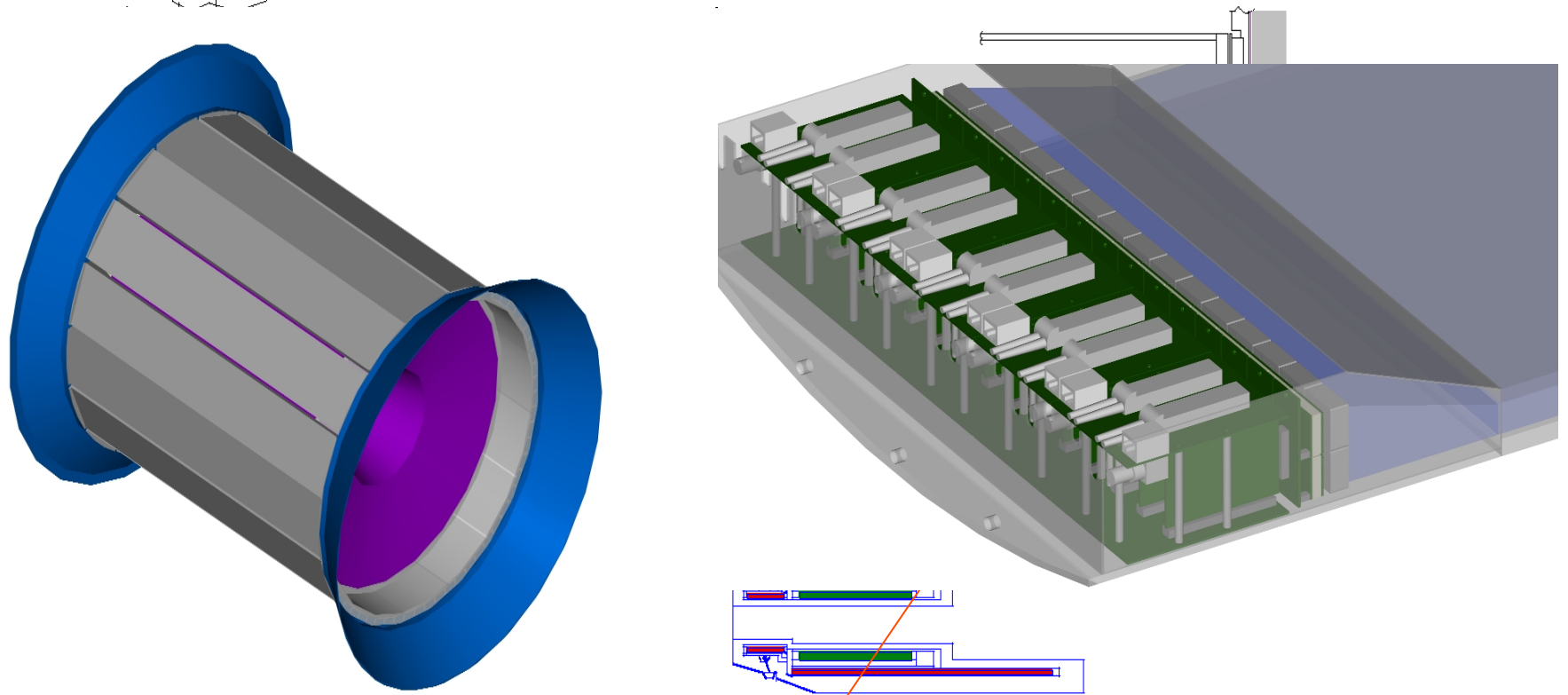
Radiation damage and occupancy

Pixel detector (Germany, Czech Republic)

**Higher event rate ( $\times 50$ )**



# High Momentum PID at Belle-II



both using Cherenkov light:

Barrel: **Time-Of-Propagation (iTOP)** (baseline), (major US contributions to quartz, readout electronics, mechanics, optics), collaboration with Nagoya and KEK

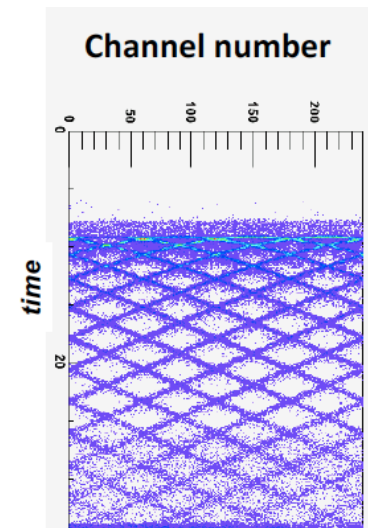
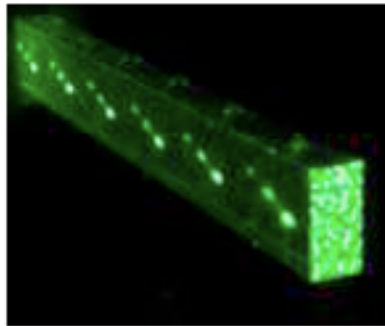
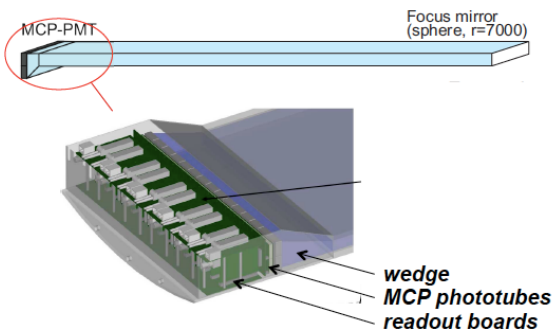
Endcap: **proximity focusing aerogel RICH** (Slovenia, KEK, Nagoya)

## 結論

*SuperKEKB starts in 2014 with an international detector collaboration (Belle-II). [Talks by Yamauchi, Suzuki]*

*The project is designed to **discover** new **FCNC** and new sources of **CPV**. The physics program is deep, broad and should help elucidate new physics found at the LHC.*

The US groups, SLAC, Nagoya and KEK are conducting R+D on the high momentum PID device as well as the scintillator based muon upgrade and beamstrahlung monitor.



*2-d probability density function*

# Backup Slides

# Belle collaboration

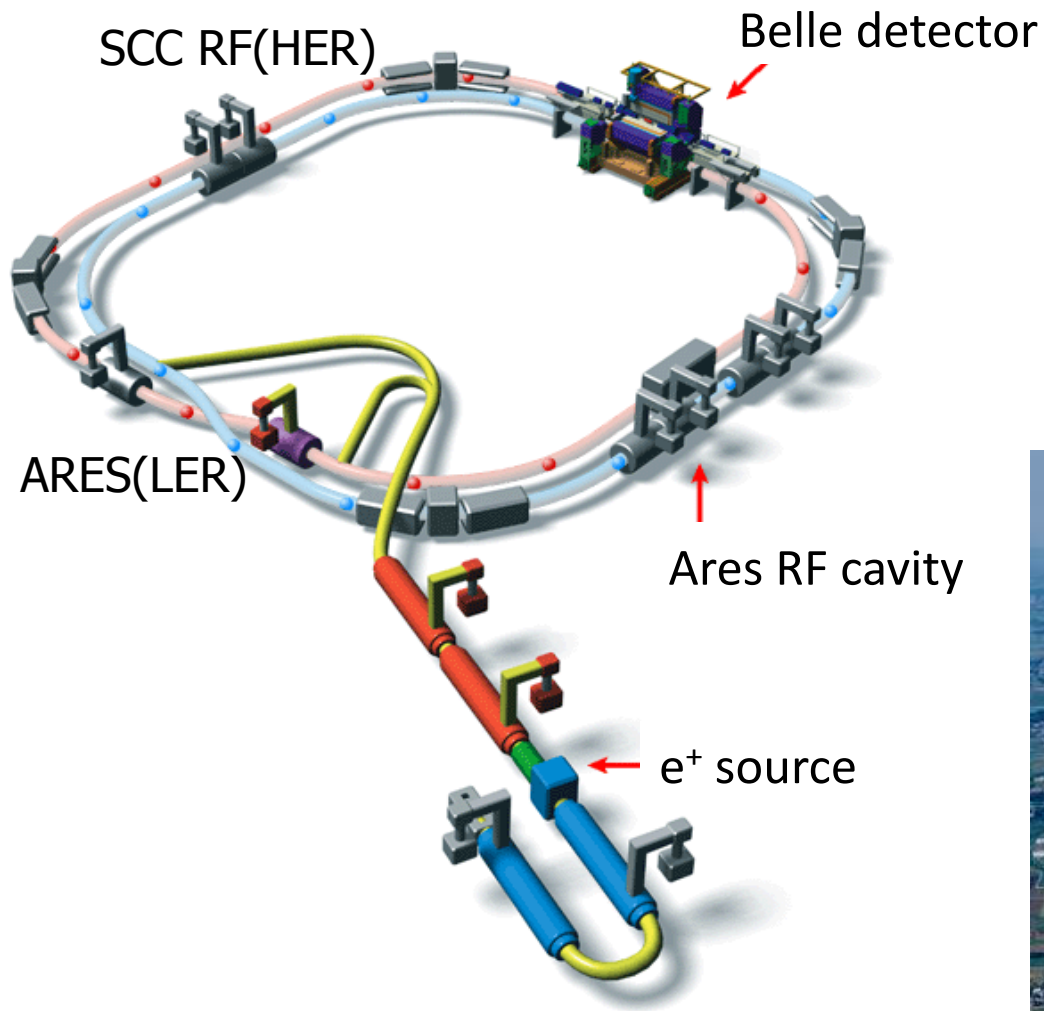



Aomori U.	IHEP, Vienna	Nagoya U.	Seoul National U.
BINP	ITEP	Nara Women's U.	Shinshu U.
Chiba U.	Kanagawa U.	National Central U.	Sungkyunkwan U.
Chonnam Nat'l U.	KEK	National Taiwan U.	U. of Sydney
<b>U. of Cincinnati</b>	Korea U.	National United U.	Tata Institute
<b>(1998-)</b>	Krakow Inst. of Nucl. Phys.	Nihon Dental College	Toho U.
Ewha Womans U.	Kyoto U.	Niigata U.	Tohoku U.
Frankfurt U.	Kyungpook Nat'l U.	Osaka U.	Tohoku Gakuin U.
Gyeongsang Nat'l U.	EPF Lausanne	Osaka City U.	U. of Tokyo
<b>U. of Hawaii</b>	Jozef Stefan Inst. / U.	Panjab U.	Tokyo Inst. of Tech.
<b>(founding member)</b>	Ljubljana / U. of Maribor	Peking U.	Tokyo Metropolitan U.
Hiroshima Tech.	U. of Melbourne	U. of Pittsburgh	Tokyo U. of Agri. and Tech.
IHEP, Beijing		<b>Princeton U.</b>	Toyama Nat'l College
IHEP, Moscow		<b>(founding member)</b>	U. of Tsukuba
		Riken	<b>VPI</b>
		Saga U.	<b>(founding member)</b>
		USTC	<b>Wayne State</b>
			<b>(2008-)</b>
			Yonsei U.

Truly International

**~14 nations, 55 institutes, ~400 collaborators**

# The KEKB Collider (Tsukuba, Japan)



8 x 3.5 GeV  
22 mrad crossing angle

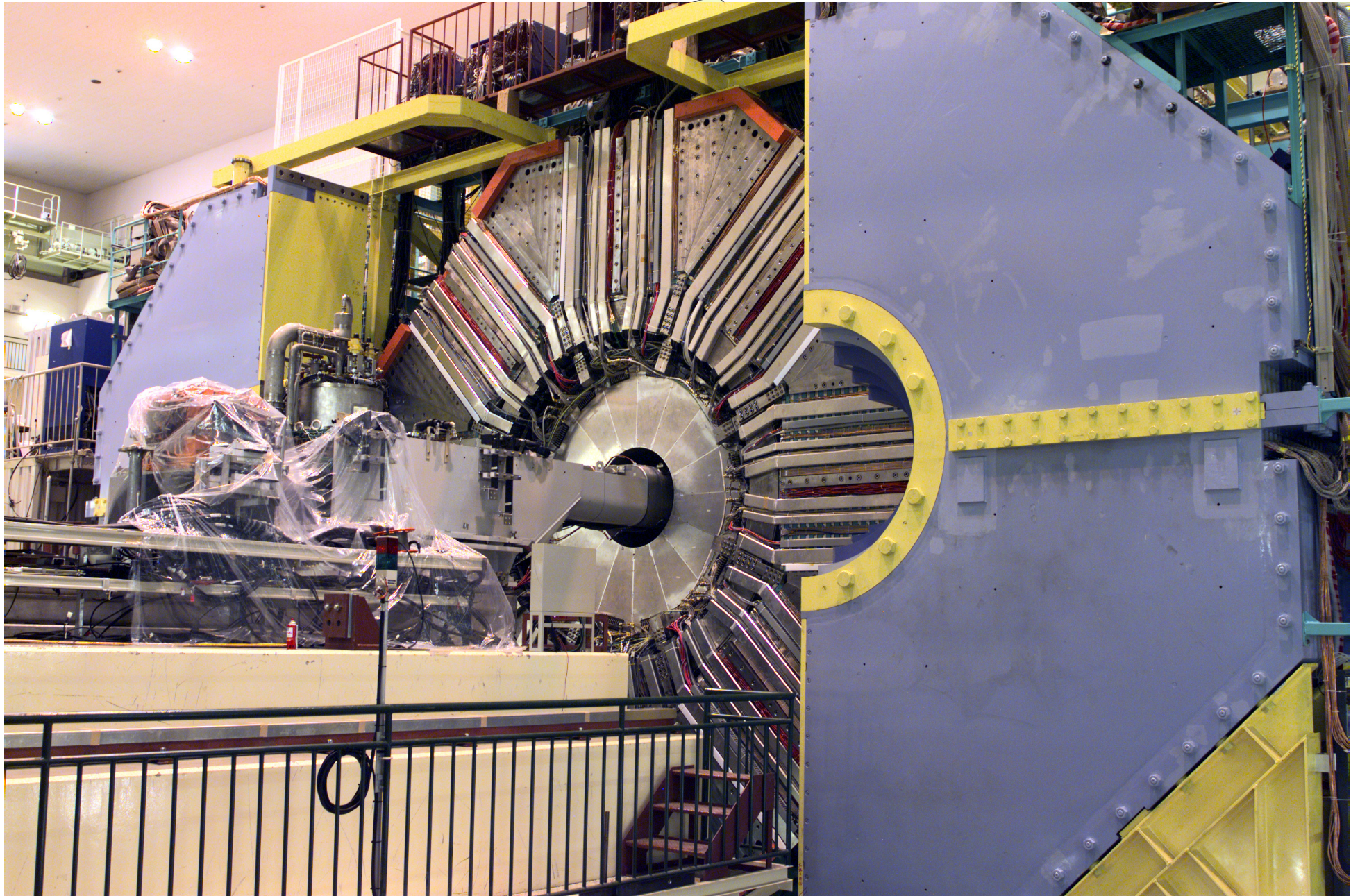
World record:

$$L = 1.7 \times 10^{34} / \text{cm}^2 / \text{sec}$$



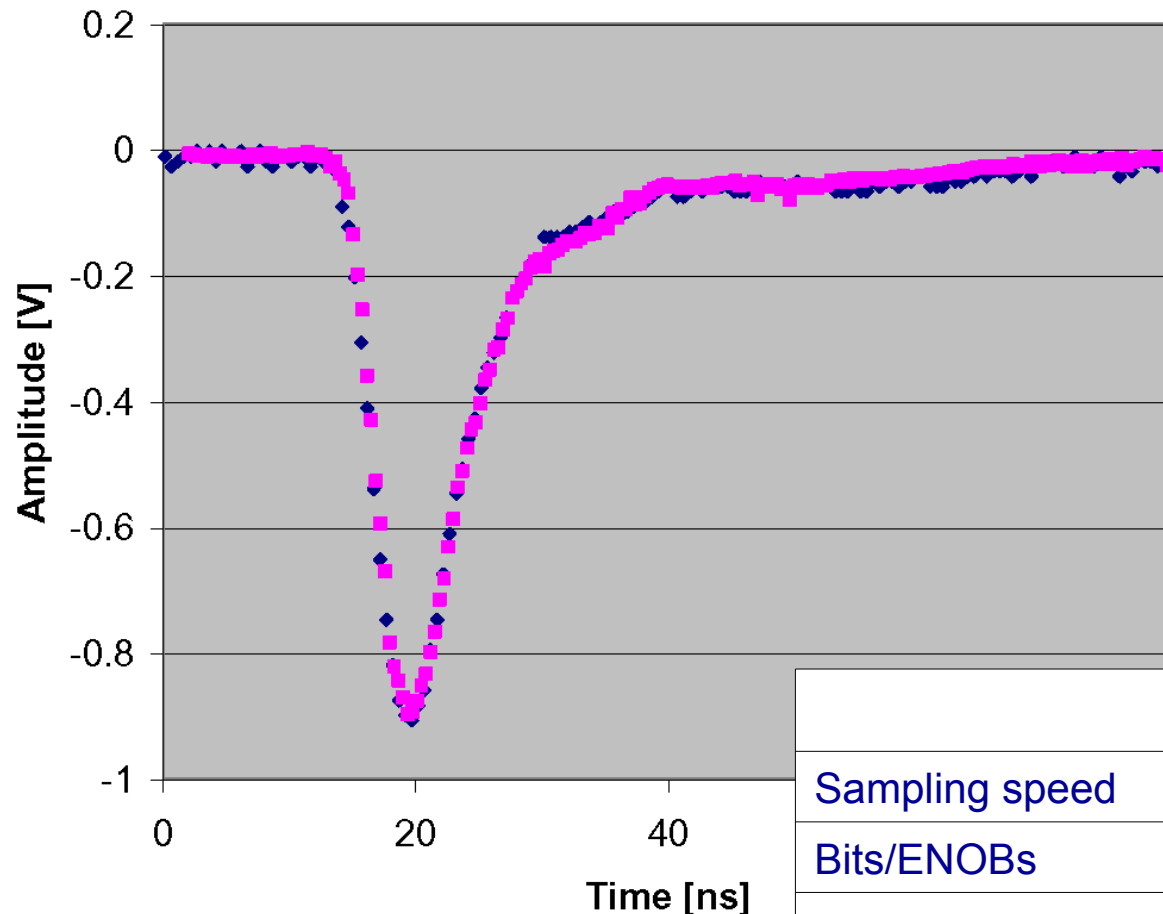
Goldrush Bar/Rakura Izakaya

# Belle Detector



## *“Oscilloscope on a Chip”*

PMT pulse comparison



Want to do high speed waveform sampling on a large number of channels in an economical way. This will be applied to timing for high luminosity PID (f-DIRC or TOP)

◆ scope [2GSa/s]  
■ STUD [2.56GSa/s]

日米 Labrador chip developed by Varner et al at Hawaii

	LABRADOR	Commercial
Sampling speed	1-3.7 GSa/s	2 GSa/s
Bits/ENOBs	12/9-10	8/7.4
Power/Chan.	$\leq 0.05$ W	5-10 W
Cost/Ch.	\$10	> 1k\$

*The most compelling hint for new physics in the weak interaction is the BAU*

$$\frac{n_{\mathcal{B}}}{n_{\gamma}} = (5.1^{+0.3}_{-0.2}) \times 10^{-10} \quad \text{WMAP}$$

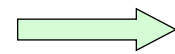
$$\text{KM} \sim 10^{-20}$$

Too small by 10 orders of magnitude in the SM

Why? Jarlskog Invariant in the SM (only 3 generations in KM)

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2) A$$

Normalize by  $T \sim 100 \text{ GeV}$



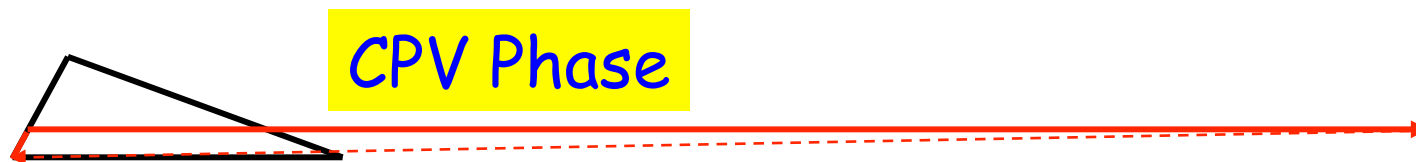
$$J/T^{12} \sim 10^{-20}$$

Mass factors in J too small !

$$A \sim 3 \times 10^{-5}$$

in SM

is common (unique) area of triangle



Credit: W.S. (George) Hou



# *The Accelerator and the Detector*

For the SuperKEKB/Belle II Super Flavor Factory



# Comparison of Parameters for KEKB and SuperKEKB

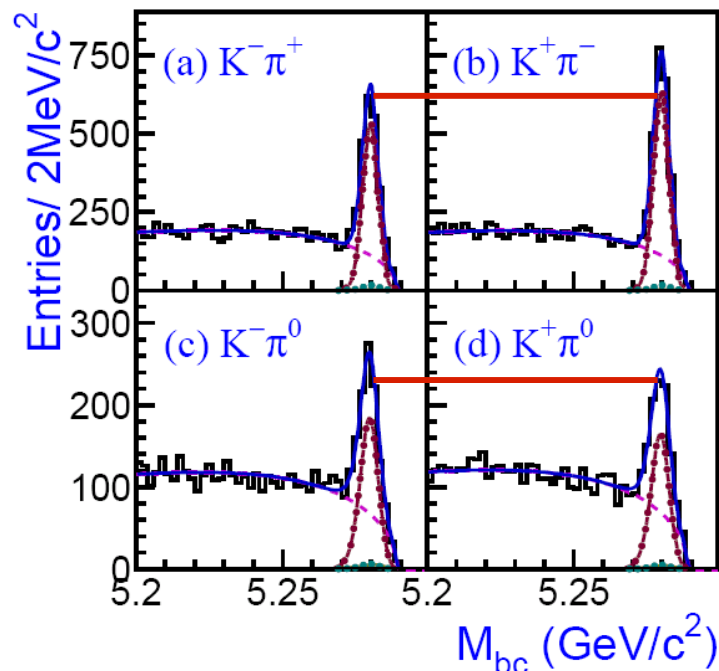
	KEKB Design	KEKB Achieved with crabs	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
$\beta_y^*$ (mm)	10/10	5.9/5.9	0.27/0.41
$\epsilon_x$ (nm)	18/18	18/24	3.2/2.4
$\sigma_y$ ( $\mu\text{m}$ )	1.9	0.94	0.059
$\xi_y$	0.052	0.129/0.090	0.09/0.09
$\sigma_z$ (mm)	4	~ 6	6/5
$I_{\text{beam}}$ (A)	2.6/1.1	1.64/1.19	3.6/2.62
$N_{\text{bunches}}$	5000	1584	2503
Luminosity ( $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ )	1	2.11	80



# Direct CP Violation in $B \rightarrow K\pi$ Decays (NP Hint ?)

$$\mathcal{A}_{CP}(B \rightarrow f) = \frac{|\bar{A}|^2 - |A|^2}{|\bar{A}|^2 + |A|^2} \propto \sum_{i,j} A_i A_j \sin(\delta_i - \delta_j) \sin(\phi_i - \phi_j)$$

**Belle Results: Nature 452, 332 (2008)**



Recent Update

$$A_{cp}(K^+\pi^-) = \begin{cases} -0.107 \pm 0.016^{+0.006}_{-0.004} & \text{BaBar} \\ -0.094 \pm 0.018 \pm 0.008 & \text{Belle} \\ -0.086 \pm 0.023 \pm 0.009 & \text{CDF} \\ -0.04 \pm 0.16 \pm 0.02 & \text{CLEO} \end{cases}$$

$\Rightarrow -0.098^{+0.012}_{-0.011} @ 8.1\sigma$  AVG

$$A_{cp}(K^+\pi^0) = \begin{cases} +0.030 \pm 0.039 \pm 0.010 & \text{BaBar} \\ +0.07 \pm 0.03 \pm 0.01 & \text{Belle} \\ -0.29 \pm 0.23 \pm 0.02 & \text{CLEO} \end{cases}$$

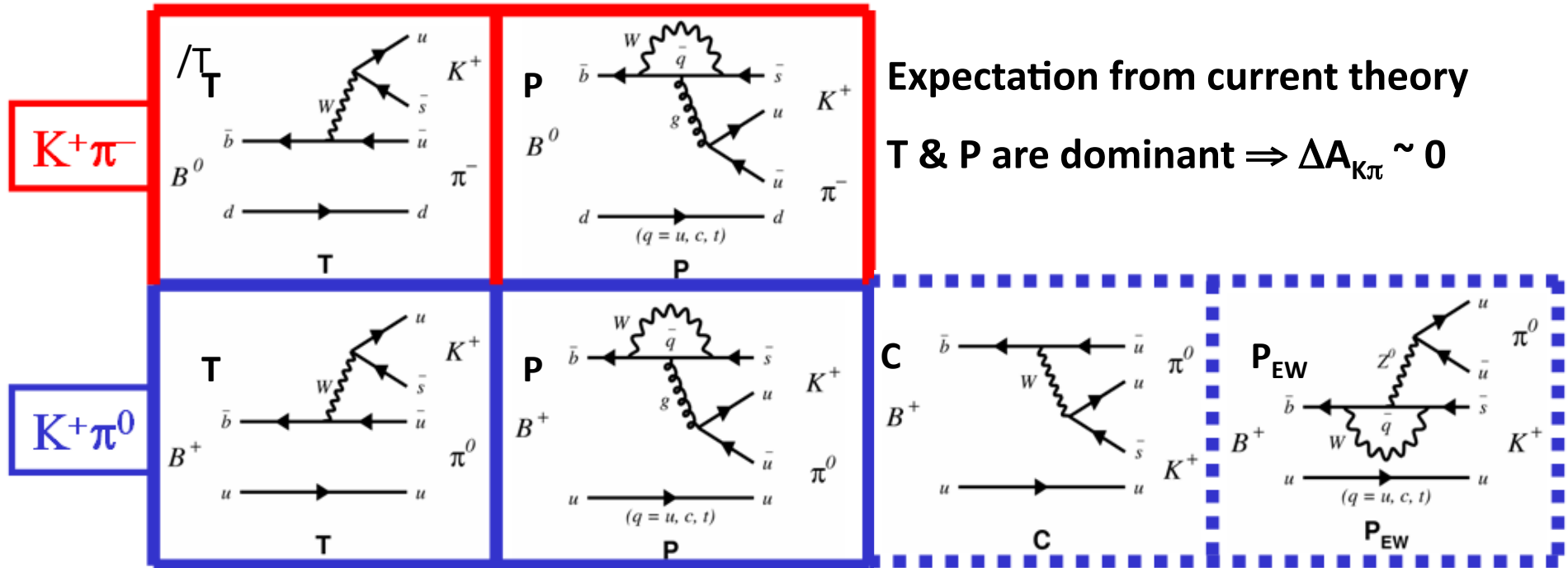
$\Rightarrow +0.050 \pm 0.025 @ 2.0\sigma$  AVG

$$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0)$$

$$= -0.147 \pm 0.028 @ 5.3\sigma$$

# Solutions to the $\Delta A_{K\pi}$ Puzzle

See Nature commentary by Michael Peskin



- Enhancement of large C with large strong phase to T  $\Rightarrow$  strong inter. !?

Chiang et. al. 2004

Li, Mishima & Sanda 2005

- Enhancement of large  $P_{EW}$   
 $\Rightarrow$  New physics

Yoshikawa 2003; Mishima & Yoshikawa 2004;

Buras et. al. 2004, 2006; Baek & London 2007;

Hou et. al. 2007; Feldmann, Jung & Mannel 2008

*Can this issue be resolved in a model-independent way by experiment ?*

# Model independent detection of NP in the $B \rightarrow K \pi$ system

$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+) \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0) \frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0) \frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

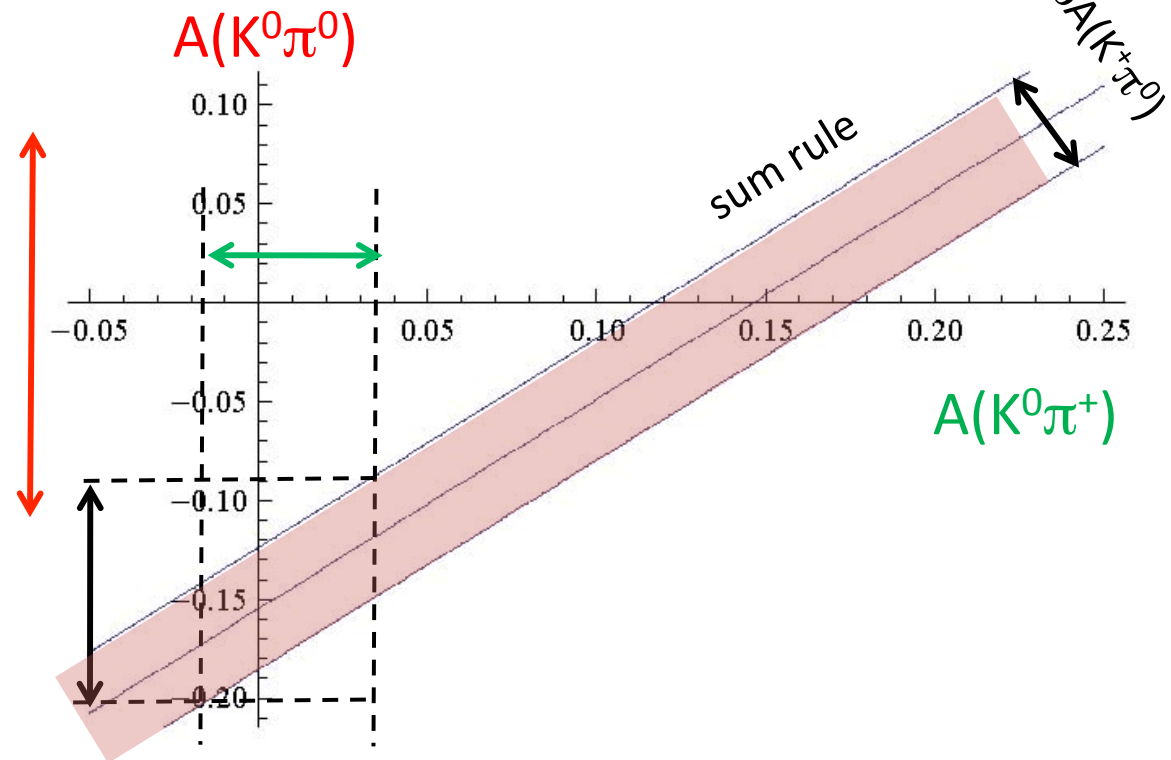
$B \rightarrow K\pi$

HFAG, ICHEP08

$A(K^0\pi^+) = 0.009 \pm 0.025$   
 $A(K^+\pi^0) = 0.050 \pm 0.025$   
 $A(K^+\pi^-) = -0.098 \pm 0.012$   
 $A(K^0\pi^0) = -0.01 \pm 0.10$

measured (HFAG)

expected (sum rule)

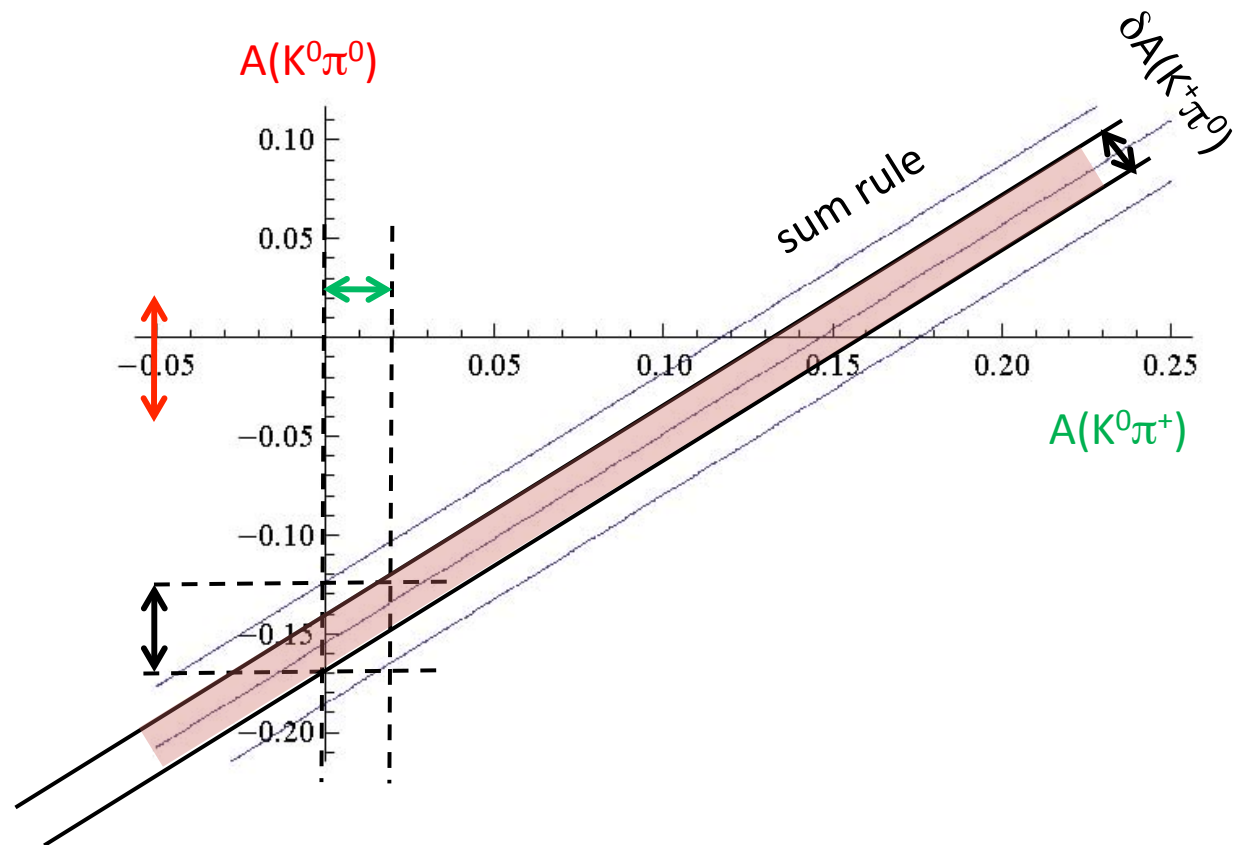


Sum rule proposed by:

M. Gronau, PLB 627, 82 (2005); D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998).

# *Model independent detection of NP in the $B \rightarrow K \pi$ system at coming Super B factories*

e.g. Belle-II, 50  $\text{ab}^{-1}$



$B \rightarrow K^0\pi^0$  :  
main syst. uncertainty  
full systematics treated  
as non-scaling (conservative)

## *D mixing: Another new physics phase !*

$$\varphi \sim \frac{2\eta A^2 \lambda^5}{\lambda} \sim O(10^{-3})$$

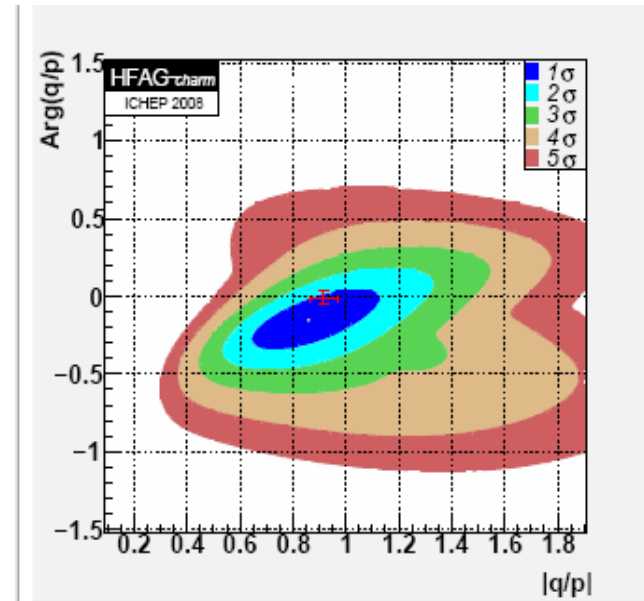
CPV in D system negligible in SM

CPV in interf. mix./decay:

$$\text{Im} \frac{q}{p} \frac{\bar{A}_f}{A_f} \equiv \left(1 + \frac{A_M}{2}\right) e^{i\varphi} \neq 0; \varphi \neq 0$$

*The existence of D mixing (if  $x$  is non-zero) allows us to look for another unconstrained new physics phase but this time from up-type quarks.*

(c.f. CPV in  $B_s$  mixing)

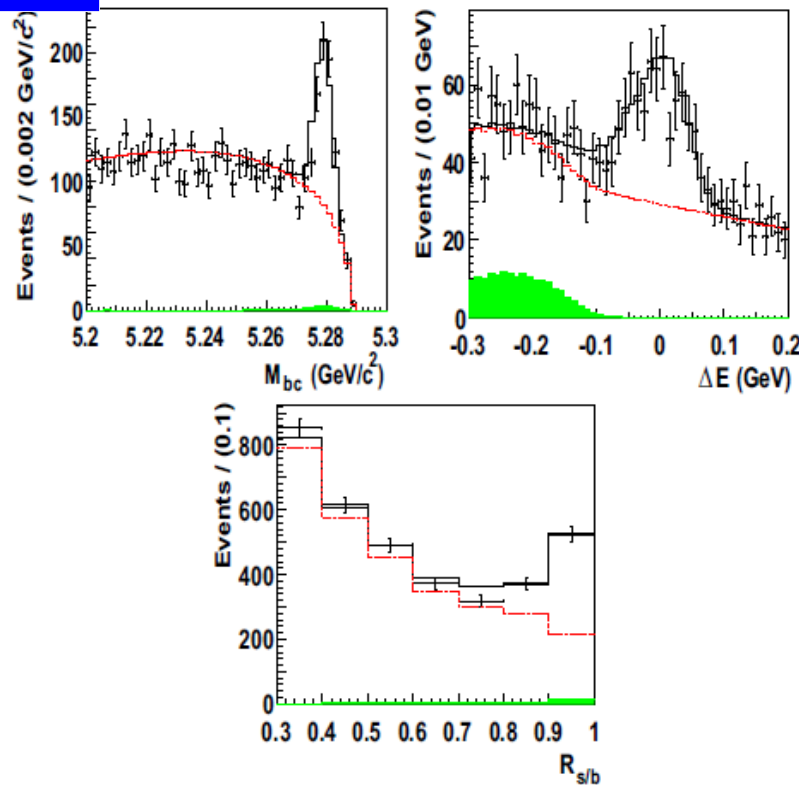


Current sensitivity  $\sim \pm 20^\circ$ , 50 ab<sup>-1</sup> go below  $2^\circ$

One important but *poorly constrained* piece in the puzzle



$B \rightarrow K_S \pi^0$  Signal

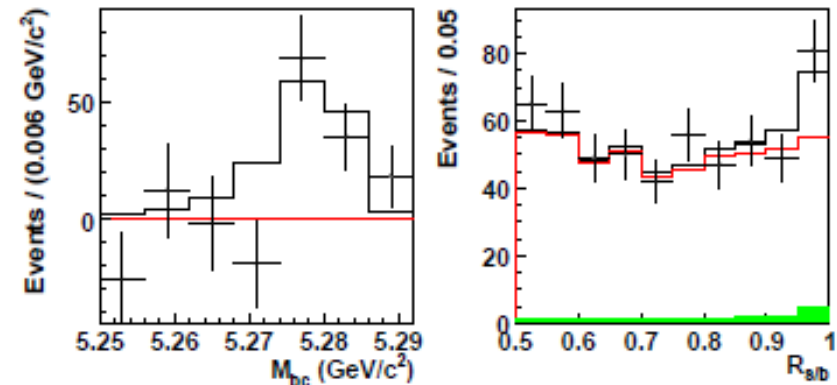


3-d fit gives a signal of  $657 \pm 37$  events

Use flavor tagging to distinguish  $B^0$  and anti- $B^0$

(Using  $K_S$  decays that are inside the silicon, we measure TCPV)

+1<sup>st</sup>  $B \rightarrow K_L \pi^0$  Signal



$285 \pm 52 \pm 57$  ( $3.7\sigma$  incl. systematics)

***These modes will be very difficult at a hadron machine***

# Lepton Flavour Violation (LFV) in the tau sector

- Highly suppressed in the SM

$$B(\tau \rightarrow l\gamma) = \frac{3\alpha}{32\pi} \left| \sum_i U_{\tau i}^* U_{li} \frac{\Delta_{3i}^2}{m_W^2} \right|^2 \leq 10^{-53} \sim 10^{-49}$$

- In some BSM (SUSY, little Higgs) LFV  $\sim O(10^{-9}-10^{-7})$
- With  $50 \text{ ab}^{-1}$  sensitivity will reach  $O(10^{-9})$

$BF(\tau \rightarrow \mu\gamma) \sim 10^{-8}$

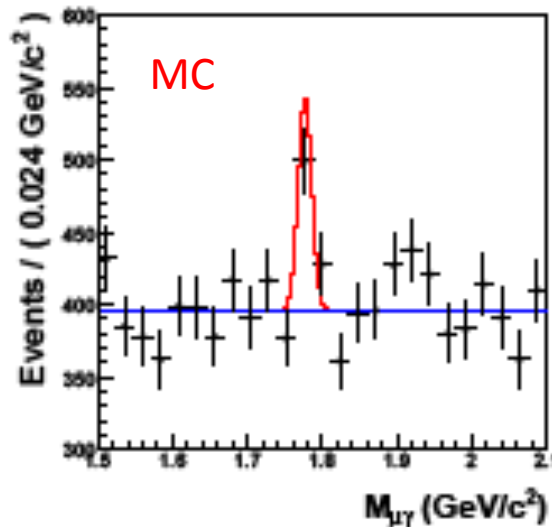
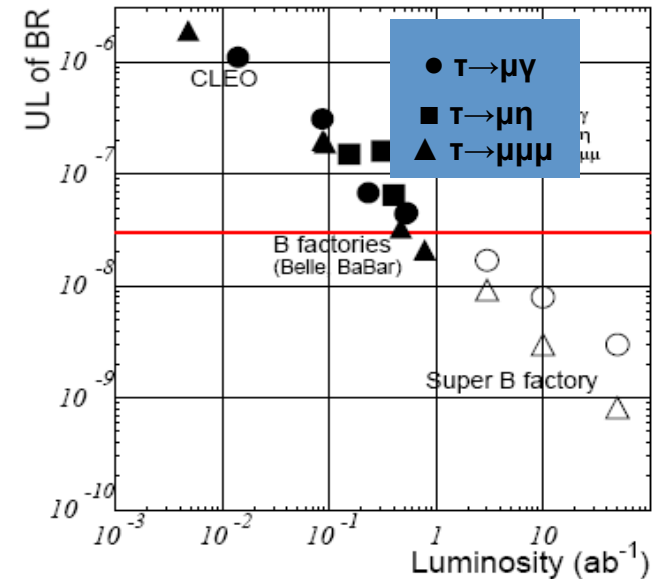


Fig. 2: Monte Carlo simulation of the appearance of  $\tau \rightarrow \mu\gamma$  at a BFF. A clear peak in the  $\mu\gamma$  invariant mass distribution is visible above the background. The branching fraction used in the simulation is  $B(\tau \rightarrow \mu\gamma) = 10^{-8}$ , an order of magnitude below the current upper limit. With  $75 \text{ ab}^{-1}$  of data the significance of such a decay is expected to exceed  $5\sigma$ .



Will be difficult at a hadron collider

*KEK is moving ahead with a Super B Factory. SuperKEKB starts in 2014 with an international detector collaboration (Belle-II). The project is approved. The laboratory and manpower are already in place; many nations have already committed; the funding is partially assembled. KEKB and Belle have a track record of exceeding expectations.*

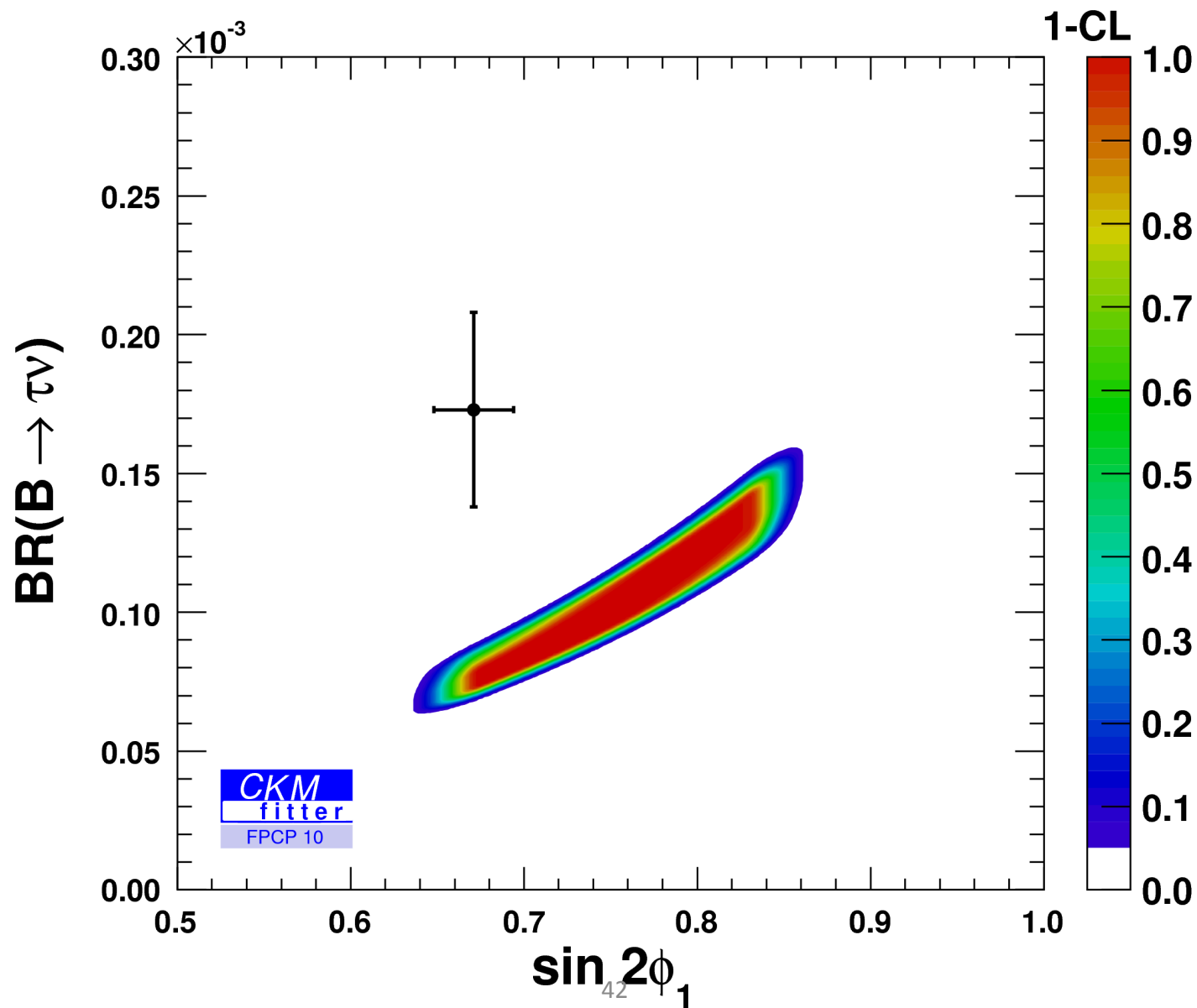
*The project is designed to **discover** new **FCNC** and new sources of **CPV**. The physics program is deep, broad and should help elucidate new physics found at the LHC.*

The US groups propose a *leadership role* in the high momentum PID device, the scintillator based muon upgrade and beamstrahlung monitor.

## Belle II/ LHCb comparisons (part I)

Observable	Belle 2006 ( $\sim 0.5 \text{ ab}^{-1}$ )	Belle II/SuperKEKB ( $5 \text{ ab}^{-1}$ )      ( $50 \text{ ab}^{-1}$ )		LHCb <sup>†</sup> ( $2 \text{ fb}^{-1}$ )      ( $10 \text{ fb}^{-1}$ )	
Hadronic $b \rightarrow s$ transitions					
$\Delta \mathcal{S}_{\phi K^0}$	0.22	0.073	0.029	0.14	
$\Delta \mathcal{S}_{\eta' K^0}$	0.11	0.038	0.020		
$\Delta \mathcal{S}_{K_S^0 K_S^0 K_S^0}$	0.33	0.105	0.037	-	-
$\Delta \mathcal{A}_{\pi^0 K_S^0}$	0.15	0.072	0.042	-	-
$\mathcal{A}_{\phi\phi K^+}$	0.17	0.05	0.014		
$\phi_1^{eff}(\phi K_S)$ Dalitz		$3.3^\circ$	$1.5^\circ$		
Radiative/electroweak $b \rightarrow s$ transitions					
$\mathcal{S}_{K_S^0 \pi^0 \gamma}$	0.32	0.10	0.03	-	-
$\mathcal{B}(B \rightarrow X_s \gamma)$	13%	7%	6%	-	-
$A_{CP}(B \rightarrow X_s \gamma)$	0.058	0.01	0.005	-	-
$C_9$ from $A_{FB}(B \rightarrow K^* \ell^+ \ell^-)$	-	11%	4%	7%	
$C_{10}$ from $A_{FB}(B \rightarrow K^* \ell^+ \ell^-)$	-	13%	4%		
$C_7/C_9$ from $A_{FB}(B \rightarrow K^* \ell^+ \ell^-)$	-		5%		
$R_K$		0.07	0.02	0.043	
$\mathcal{B}(B^+ \rightarrow K^+ \nu \nu)$	$\dagger\dagger < 3 \mathcal{B}_{\text{SM}}$		30%	-	-
$\mathcal{B}(B^0 \rightarrow K^{*0} \nu \bar{\nu})$	$\dagger\dagger < 40 \mathcal{B}_{\text{SM}}$		35%	-	-
Radiative/electroweak $b \rightarrow d$ transitions					
$\mathcal{S}_{\rho\gamma}$	-	0.3	0.15		
$\mathcal{B}(B \rightarrow X_d \gamma)$	-	24% (syst.)			

## Intriguing Tension in SM observables

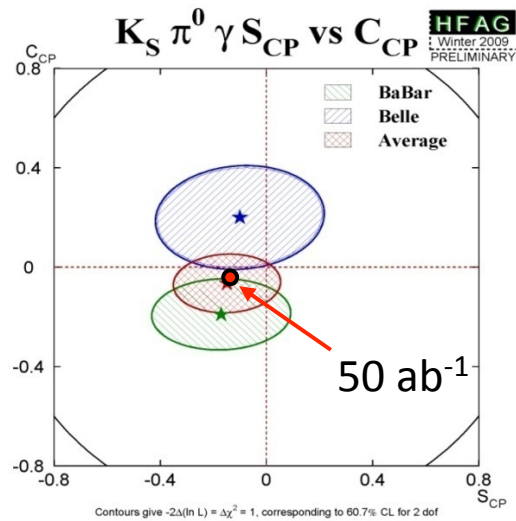


## Belle II/ LHCb comparisons (part II)

Observable	Belle 2006 ( $\sim 0.5 \text{ ab}^{-1}$ )	Belle II/SuperKEKB ( $5 \text{ ab}^{-1}$ )	( $50 \text{ ab}^{-1}$ )	LHCb <sup>†</sup> ( $2 \text{ fb}^{-1}$ )	( $10 \text{ fb}^{-1}$ )	
Leptonic/semileptonic $B$ decays						
$\mathcal{B}(B^+ \rightarrow \tau^+ \nu)$	$3.5\sigma$	10%	$\left\{ \begin{array}{c} 3\% \\ 4.3 \text{ ab}^{-1} \text{ for } 5\sigma \text{ discovery} \\ 8\% \\ 30\% \end{array} \right\}$	-	-	
$\mathcal{B}(B^+ \rightarrow \mu^+ \nu)$	$^{\dagger\dagger} < 2.4\mathcal{B}_{\text{SM}}$			-	-	
$\mathcal{B}(B^+ \rightarrow D\tau\nu)$	-	8%		3%	-	-
$\mathcal{B}(B^0 \rightarrow D\tau\nu)$	-	30%		10%	-	-
LFV in $\tau$ decays (U.L. at 90% C.L.)						
$\mathcal{B}(\tau \rightarrow \mu\gamma) [10^{-9}]$	45	10	5	-	-	
$\mathcal{B}(\tau \rightarrow \mu\eta) [10^{-9}]$	65	5	2	-	-	
$\mathcal{B}(\tau \rightarrow \mu\mu\mu) [10^{-9}]$	21	3	1	-	-	
Unitarity triangle parameters						
$\sin 2\phi_1$	0.026	0.016	0.012	$\left\{ \begin{array}{cc} \sim 0.02 & \sim 0.01 \\ - & - \\ 10^\circ & 4.5^\circ \\ - & - \\ 10^\circ & 4.5^\circ \\ 8^\circ \\ 5\text{-}15^\circ \\ 4.2^\circ & 2.4^\circ \\ - & - \\ - & - \end{array} \right\}$		
$\phi_2 (\pi\pi)$	$11^\circ$	$10^\circ$	$3^\circ$			
$\phi_2 (\rho\pi)$	$68^\circ < \phi_2 < 95^\circ$	$3^\circ$	$1.5^\circ$			
$\phi_2 (\rho\rho)$	$62^\circ < \phi_2 < 107^\circ$	$3^\circ$	$1.5^\circ$			
$\phi_2$ (combined)		$2^\circ$	$\lesssim 1^\circ$			
$\phi_3 (D^{(*)}K^{(*)})$ (Dalitz mod. ind.)	$20^\circ$	$7^\circ$	$2^\circ$			
$\phi_3 (DK^{(*)})$ (ADS+GLW)	-	$16^\circ$	$5^\circ$			
$\phi_3 (D^{(*)}\pi)$	-	$18^\circ$	$6^\circ$			
$\phi_3$ (combined)		$6^\circ$	$1.5^\circ$			
$ V_{ub} $ (inclusive)	6%	5%	3%			
$ V_{ub} $ (exclusive)	15%	12% (LQCD)	5% (LQCD)			
$\bar{\rho}$	20.0%		3.4%			
$\bar{\eta}$	15.7%		1.7%			

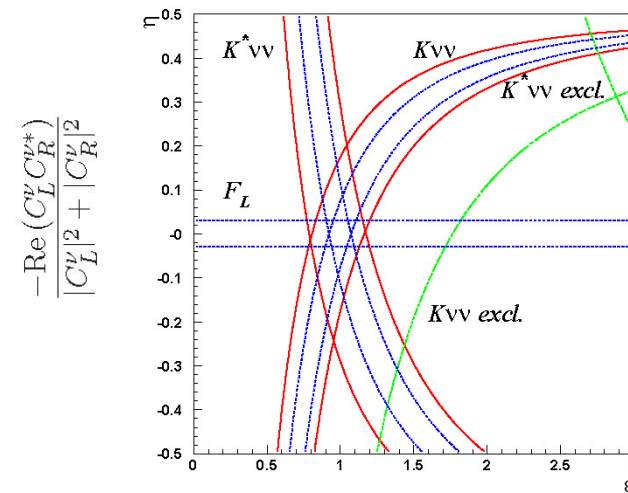
# A few more physics examples

## Precision measurement



$B \rightarrow K^* \gamma$ ,  $B \sim 4 \times 10^{-5}$   
 $dS \sim 0.2 \rightarrow \sim \text{a few \%}$ , at a SFF

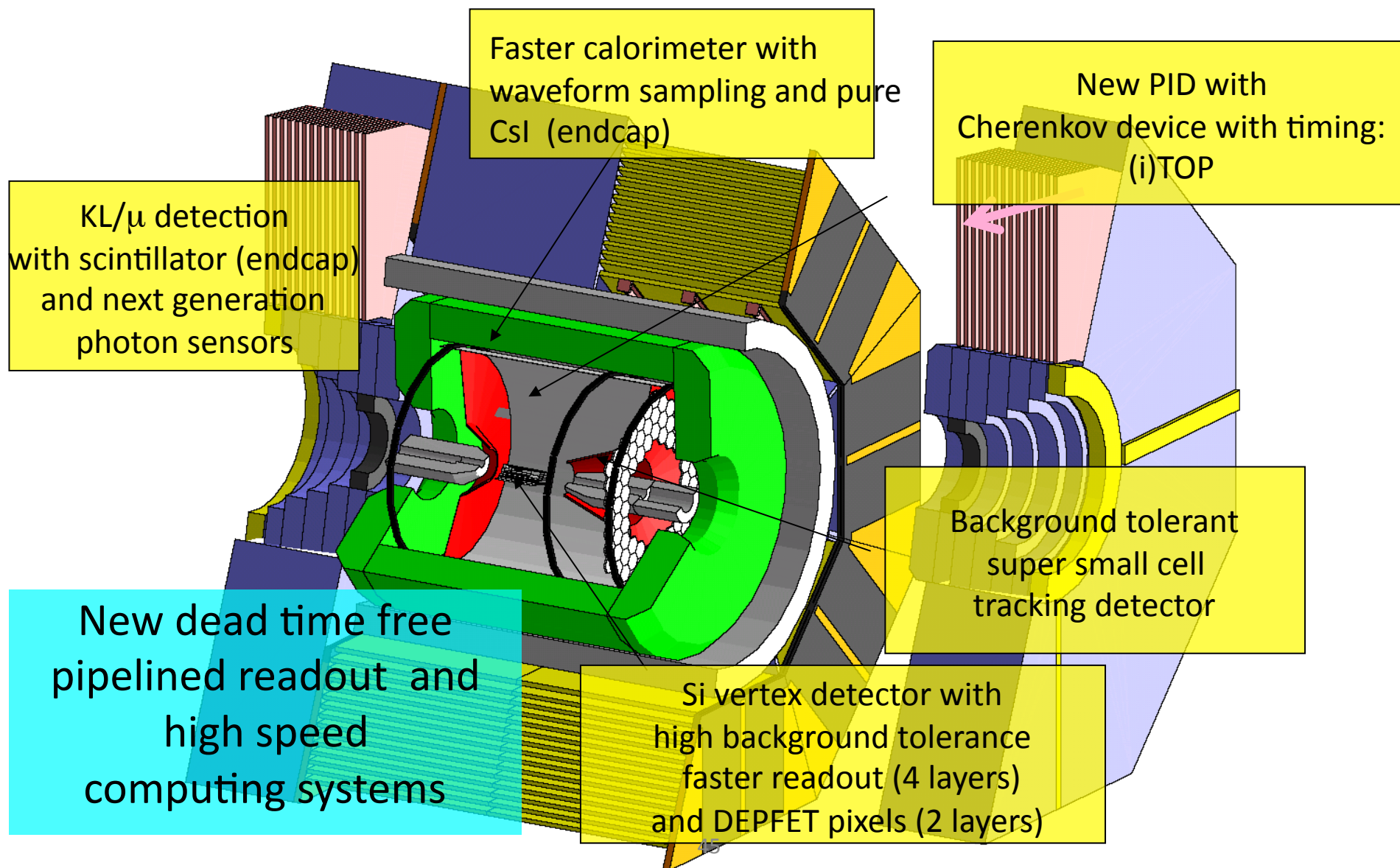
## Discover a new mode



adopted from W. Altmannshofer et al.,  
 JHEP 0904, 022 (2009)

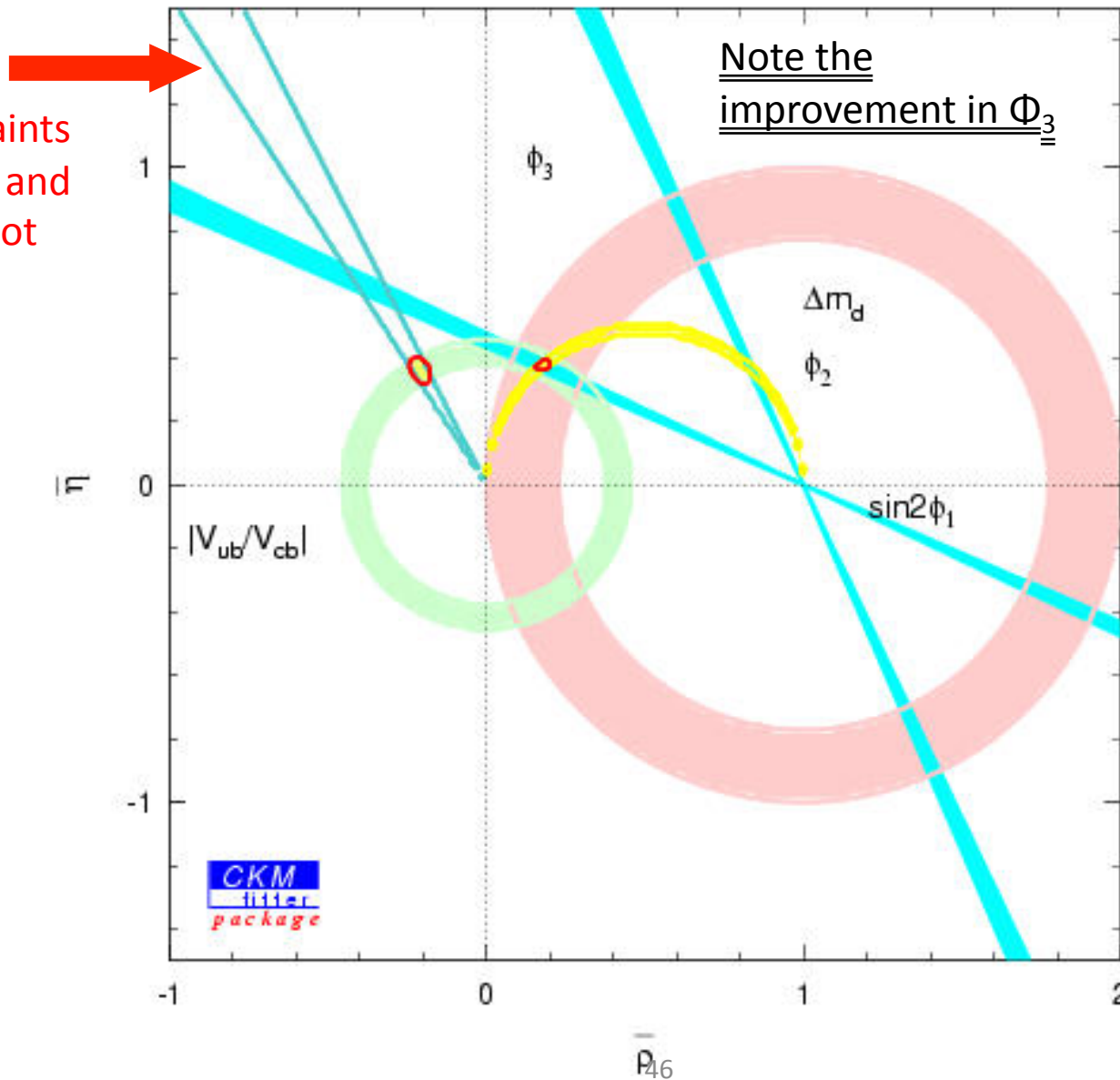
$B \rightarrow K \nu \nu$ ,  $B \sim 4 \cdot 10^{-6}$

# *Super Belle: A detector for SuperKEKB*



# New Physics might appear like this @50 $ab^{-1}$

NB Constraints from trees and boxes do not agree







This would indicate that there is a **NP phase** in  $b \rightarrow d$

50  $ab^{-1}$

# Super B Factory vs current sensitivities

Hard to condense all the NP observables into one sound bite.....

Observable	SFF sensitivity	Current sensitivity
$\sin(2\beta) (J/\psi K^0)$	0.005-0.012	0.01
$\gamma (DK)$	1-2°	$\sim 31^\circ$ (CKMFitter)
$\alpha (\pi\pi, \rho\pi, \rho\rho)$	1-2°	$\sim 15^\circ$ (CKMFitter)
$ V_{ub} (\text{excl})$	3-5%	$\sim 18\%$ (PDG review)
$ V_{ub} (\text{incl})$	2-6%	$\sim 8(PDG\text{review})\%$
$\bar{\rho}$	1.7-3.4%	+20% -12%
$\bar{\eta}$	0.7-1.7%	$\pm 4.6\%$
$S(\phi K^0)$	0.02-0.03	0.17
$S(\eta' K^0)$	0.01-0.02	0.07
$\mathcal{B}(B \rightarrow \tau \nu)$	3 - 4%	30%
$\mathcal{B}(B \rightarrow \mu \nu)$	5 - 6%	not measured 
$\mathcal{B}(B \rightarrow D \tau \nu)$	2 - 2.5%	31%
$\mathcal{B}(B \rightarrow \rho \gamma) / \mathcal{B}(B \rightarrow K^* \gamma)$	3-4%	16%
$A_{CP}(b \rightarrow s \gamma)$	0.004-0.005	0.037
$A_{CP}(b \rightarrow s \gamma + d \gamma)$	0.01	0.12
$S(K_S \pi^0 \gamma)$	0.02-0.03	0.24
$S(\rho^0 \gamma)$	0.08-0.12	0.67
$A^{FB}(B \rightarrow K^* \ell^+ \ell^-)_{s0}$	4-6%	not measured 
$\mathcal{B}(B \rightarrow K \nu \bar{\nu})$	16-20%	not measured 
$\mathcal{B}(B \rightarrow s \ell^+ \ell^-)_{s0}$		
$\mathcal{B}(B \rightarrow d \ell^+ \ell^-)_{s0}$		not measured 
$\phi_D$ (NP phase)	$\pm(1-2)^\circ$	$\sim \pm 20^\circ$
$\mathcal{B}(\tau \rightarrow \mu \gamma)$	$(2-8) \times 10^{-9}$	not seen, $< 5.0 \times 10^{-8}$
$\mathcal{B}(\tau \rightarrow \mu \mu \mu)$	$(0.2-1) \times 10^{-9}$	not seen, $< (2-4) \times 10^{-8}$
$\mathcal{B}(\tau \rightarrow \mu \eta)$	$(0.4-4) \times 10^{-9}$	not seen, $< 5.1 \times 10^{-8}$

(50-75  $ab^{-1}$  compared to current 1  $ab^{-1}$  )

From TEB et al., hep-ph/0710.3799 and RMP 81, 2009<sup>47</sup>

## What is the machine construction plan for JFY2010 ?

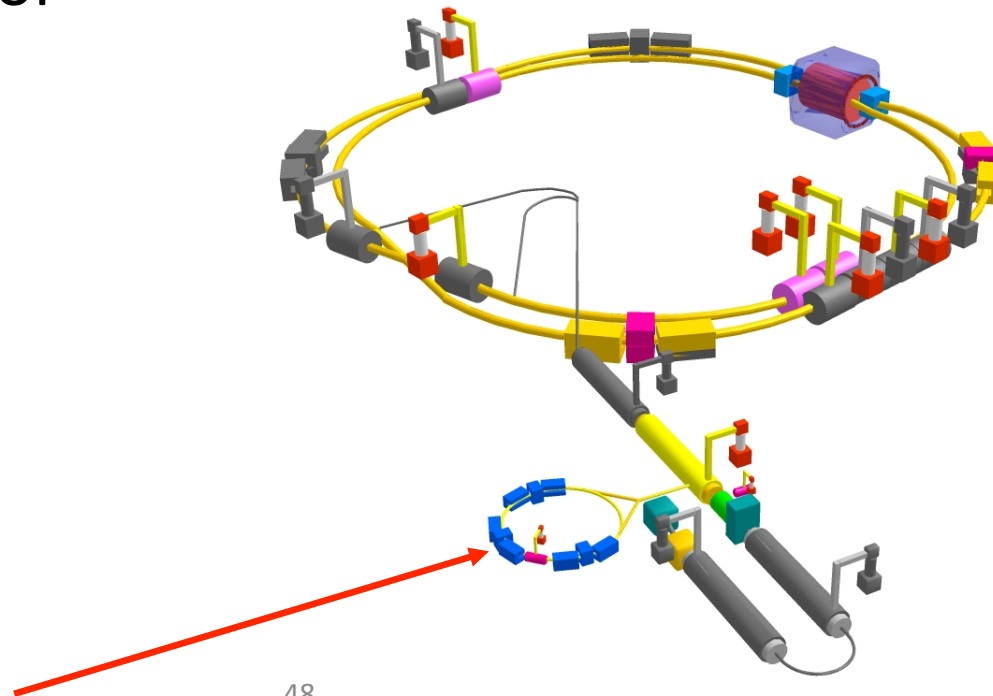
- Damping ring for the injector → First priority
- Disassemble existing KEKB. Magnets, vacuum pipes, etc. will be taken out of the tunnel.
- Start manufacturing major accelerator components.

Beam pipe

Magnets

RF system

Damping ring



“Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed” –A. Soni@SuperKEKB Proto-collaboration meeting

## *A lesson from history*

---

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single  $K_L \rightarrow \pi^+ \pi^-$  event among **600 decays** into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-**Lev Okun**, "The Vacuum as Seen from Moscow"

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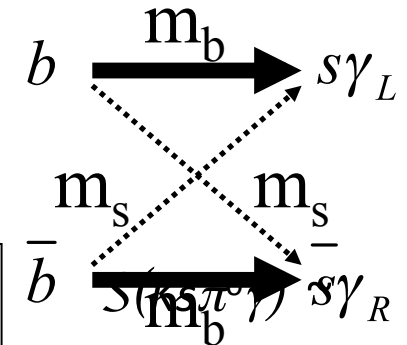
1964:  $BF = 2 \times 10^{-3}$

A failure of imagination ? Lack of patience ?

# Right-handed currents in $b \rightarrow s\gamma$

D.Atwood, M.Gronau, A.Soni, PRL79, 185 (1997)

D.Atwood, T.Gershon, M.H, A.Soni, PRD71, 076003 (2005)



- tCPV in  $B^0 \rightarrow (K_S \pi^0)_{K^*} \gamma$

- SM:  $\gamma$  is polarized, the final state almost flavor-specific.

$$-2m_s/m_b \sin 2\phi_1$$

- $m_{\text{heavy}}/m_b$  enhancement for right-handed currents in many NP models

e.g. LRSM, SUSY, Randall-Sundrum (warped extra dimension) model

- LRSM:  $SU(2)_L \times SU(2)_R \times U(1)$

- Right-handed amplitude  $\propto \zeta m_t/m_b$  :  $\zeta$  is  $W_L$ - $W_R$  mixing parameter

- for present exp. bounds ( $\zeta < 0.003$ ,  $W_R$  mass  $> 1.4\text{TeV}$ )

$$|S(K_S \pi^0 \gamma)| \sim$$

0.5 is allowed.

- **N.B. No need for a new CPV phase**

**Photon polarization measurement via time dependent CPV**

## *Why a flavor factory is so important:*

- *A flavor factory studies processes that occur at 1-loop in the SM but may be  $O(1)$  in NP: FCNC, neutral meson mixing, CP violation. These loops probe energy scales that cannot be accessed directly (even at the LHC).*
- *Current experimental bounds NP scale is 10-100 TeV; thus, if the LHC finds NP at  $O(1)$  TeV, it must have a nontrivial flavor/phase structure*
- *Even if no new sources of CPV or flavor violation, current SM couplings are sufficient to provide sensitivity to new particles at a super flavor factory*
- *SM CP violation is insufficient to account for baryogenesis of matter-dominated universe; must be other sources of CPV*
- *If supersymmetry is found at the LHC, a crucial question will be: how is it broken. By studying flavor couplings, a flavor factory can address this.*

*A (super) flavor factory searches for NP by phases, CP asymmetries, inclusive decay processes, rare leptonic decays, absolute branching fractions. There is a wide range of observables. These are complementary to the LHC Atlas and CMS experiments, which will search for NP via direct new particle production at high- $p_T$ .*

US Role in the  
past

# *HIGG's at Belle ??*

## HIGG's= High Impact Gaijin Groups

Will restrict comments here to US Groups: Cincinnati, Hawaii, Princeton, VPI, (Illinois/RIKEN)

(Track Record of Exceeding Expectations)

Two foreign spokespersons

Two publication council (PC) members

*Construction and software of  
the KLM detector*

*Construction and software  
for the TOF*

*SVD readout, IR masking +design,  
Kalman filter*

One analysis  
coordinator

Two ICPV group leaders  
+many analyses

Discoveries of new  
particles e.g. X(3872)

Measurement of  
 $\alpha/\phi_2$

Dedicated run at  
the Upsilon(5S)

(Azimuthal spin  
asymmetries)

Many, many  
analyses.....

## **Big** issues:

- *why  $SU(2)_L \times U(1)$ ?*
- *what breaks  $SU(2)_L \times U(1)$ ?*
- *what gives particle mass?*
- *what stabilizes the electroweak scale below 1 TeV?*

⇒ **LHC**

(Atlas, CMS)

(i.e., the “energy frontier”)

but let's not forget:

- *why 3 generations? (are there more?)*
- *why are the masses so different?*
- *why the pattern of CKM weak couplings?*
- *what causes the phase in the CKM matrix?*
- *why do we live in a matter, rather than antimatter, universe?*

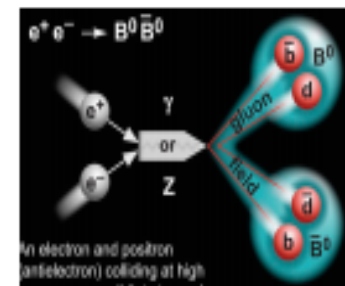
⇒ **Flavor “factory”:**

(CLEO, Belle, BaBar, CDF/D0, BESIII, Belle-II, SuperB, LHCb)

(i.e., a facility where large numbers of heavy quarks (c,b) or leptons ( $\tau$ ) are produced)

**Reminder:**

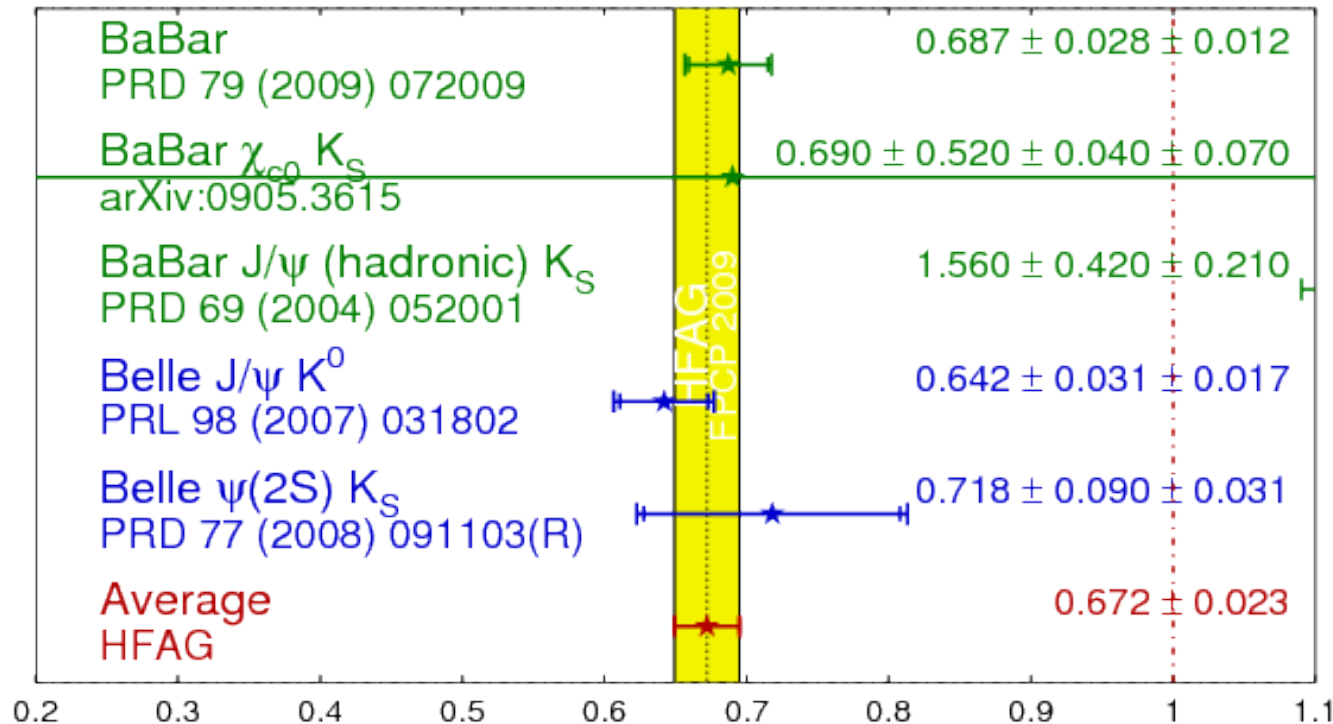
*solutions to the latter set may help us answer the first set, and vice-versa*



# BaBar + Belle

$$\sin(2\beta) \equiv \sin(2\phi_1)$$

**HFAG**  
FPCP 2009  
PRELIMINARY



*A precise measurement of the phase of  $B_d$  mixing ( $< 4\%$  error) and tomorrow's background.* - Val Telegdi  
**Reference Point for NP search**

Some popular theoretical solutions to this BAU problem and their experimental implications:

**Leptogenesis**: requires  $M \sim O(10^{10} \text{ GeV})$  RH neutrinos **AND** CP violation in the neutrino sector.

May produce lepton flavor violation such as  $\tau \rightarrow \mu \gamma$  (or  $\mu \rightarrow e$  conversion)

**“Enhanced Baryogenesis”**: add massive 4<sup>th</sup> generation quarks (e.g. Hou, Soni et al) or add new SUSY particles in the MSSM (light scalars e.g. stop). Both will lead to new CPV phases.

Phases in  $b \rightarrow s$  or  $b \rightarrow d$  mixing, anomalous EW penguins (K  $\pi$  puzzle),  $B_s$  mixing etc..

*Looking for low energy echoes of the primordial CP violation produced at **energy scales** that are beyond the reach of accelerators*

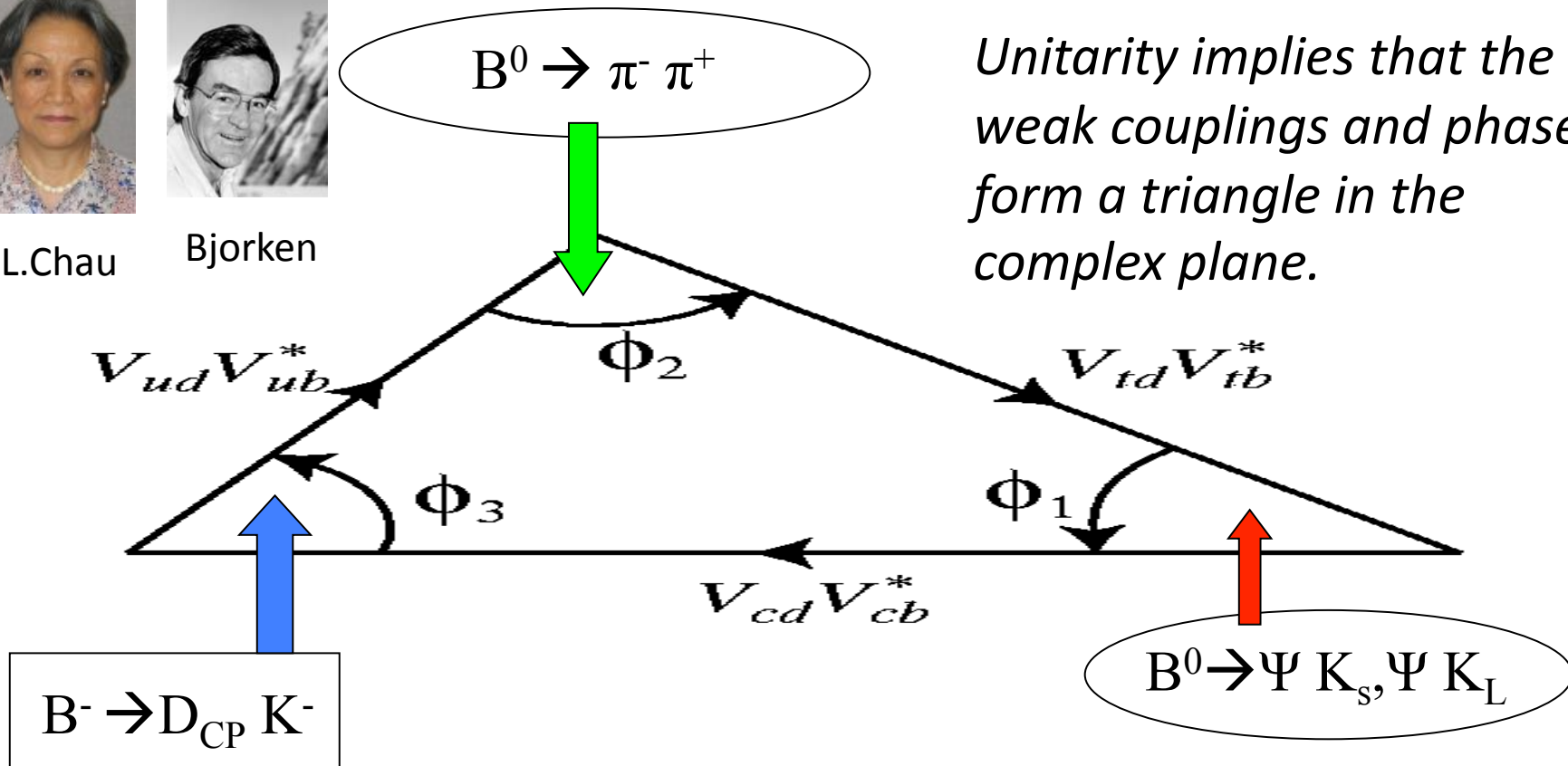
# Three Angles: $(\varphi_1, \varphi_2, \varphi_3)$ or $(\beta, \alpha, \gamma)$



L-L. Chau



Bjorken



Big Question(s): *Are determinations of angles consistent with determinations of the sides of the triangle? Are angle determinations from **loop** and **tree** decays consistent?*